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Prospects for International Management of Intercontinental Air Pollution Transport

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Abstract The recognition of the intercontinental transport of air pollution continues a historic trend towards greater awareness and management of air pollution over larger spatial scales. Intercontinental transport contributes to a "tightening vise" on air quality management in industrialized nations with background concentrations rising, standards becoming more stringent, local controls becoming more difficult to achieve, and emissions in other parts of the world rapidly increasing. While several regional and global regimes currently exist for addressing issues of transboundary air quality, important gaps remain for intercontinental transport. International cooperative regimes at all levels—binational, regional, hemispheric, and global—should be encouraged to address intercontinental transport. Activities which increase the capacity in developing nations for managing domestic air pollution problems are the most important actions to be taken in the short term. In addition, international research efforts are needed to quantify source-receptor relationships between nations and to develop integrated analysis tools that connect international transport, climate change, global energy infrastructure, and economic development.

List of Abbreviations

AMAP	Arctic Monitoring and Assessment Program
ASEAN	Association of Southeast Asian Nations
CFCs	chlorofluorocarbons
CTMs	chemical transport models
EMEP	Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollution in Europe
EANET	East Asia Network
GHGs	greenhouse gases
INDOEX	Indian Ocean Experiment
LRTAP	Long Range Transboundary Air Pollution

OECD	Organization for Economic Cooperation and Development
$PM_{2.5}$	particles less than 2.5 microns in diameter
PM_{10}	particles less than 10 microns in diameter
POPs	persistent organic pollutants
RAINS	Regional Air Pollution Information and Simulation
TSP	total suspended particulates
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States of America
VOCs	volatile organic compounds

1 Introduction

The intercontinental transport of air pollutants is a rapidly advancing field of atmospheric science, as reflected in the other chapters of this book. As our knowledge of transport evolves, our political institutions and policies to address the problem must evolve as well, raising important questions: What are appropriate policy responses to this growing scientific understanding of air pollution? What can be learned from environmental policy formation generally, and from existing international efforts to control cross-border air pollution specifically, that will be relevant for predicting and designing a policy response? Are existing international regimes sufficient for addressing intercontinental transport, or are new regimes required?

The purposes of this chapter are to discuss how the evolution of science affects the evolution of environmental policy and to analyze alternative policy responses for the case of intercontinental air pollutant transport. In particular, we discuss the difficulties of developing international regimes for addressing transboundary air pollution problems and experiences gained historically through such regimes. Here we use the word 'regime' to mean "social institutions consisting of agreed-upon principles, norms, rules, procedures, and programs that govern the interactions of actors in specific issue areas [1]," suggesting that a regime can be more than a treaty, including the whole process of interaction by which a treaty might be formed. Thus, regimes include political as well as scientific activities, such as cooperative research programs, standards and calibration organizations, and scientific assessment bodies.

We begin by setting the historical context for understanding new scientific findings about intercontinental transport, addressing how the spatial scale of air pollution has changed historically and the forces that are now pushing towards greater international linkages. We identify some of the existing international regimes for addressing the international transport of air pollutants, consider how international environmental policy regimes evolve, and identify the characteristics that are thought to be favorable for success. In light of this discussion, we consider the prospects for effectively addressing intercontinental transport through policy actions and regimes at the national, regional, and hemispheric or global scales. Finally, we discuss how air pollution science can contribute knowledge and analysis that will be relevant and useful in informing this process.

2 Changing Views of Air Pollution: the Historical Context for Intercontinental Transport

2.1 The Evolution of the Spatial Scale of "Air Pollution"

The history of air pollution science and management has been one of gradually evolving views of what air pollution is and what components of air pollution are relevant for policy action to control emissions. This shift in emphasis among different components of air pollution is a result of 1) the improvement in our scientific understanding of air pollution through time, often driven by new measurement and observation techniques, creating an awareness of new problems, and 2) the success of emissions control efforts, effectively addressing some problems and allowing other problems to come to the forefront of policy awareness.

Figure 1 shows the evolution of the problems and pollutants emphasized in air pollution science and management in the United States. The earliest efforts at air pollution management were local efforts focused on the mitigation of smoke, soot, and odors [2]. As these readily perceptible problems came under control in the 1960s, air pollution control efforts shifted focus to the control of ozone, SO_2, CO, NO_2, lead, and total suspended particulates (TSP). In the 1970s, awareness of these issues led to national ambient air quality standards, industrial controls, the removal of lead from gasoline, and the addition of catalytic converters on vehicles. Beginning in the 1970s and extending through the 1980s, attention focused on understanding acidifying deposition, eventually leading to significant SO_2 emissions controls. In the 1990s, problems such as CO came under control with changes in fuels and vehicle controls. Ozone, however, remained a stubborn problem, and the effects of changes in emissions of NO_X and volatile organic compounds (VOCs) became understood as subtle and difficult to predict [3]. Meanwhile, epidemiology developed the strongest evidence so far of the health effects of air pollution, identifying particles – first PM_{10}, then fine particles ($PM_{2.5}$) – as most responsible [4]. In the near future, there is a clear trend towards increasing concerns over emissions of mercury, airborne toxics and persistent organic pollutants (POPs), and greenhouse gases (GHGs) that contribute to climate change. In addition, the results of continuing research on the health effects of particles may focus control efforts on specific chemical components and their sources.

As this shift in focus between different pollutants has taken place, our concept of the spatial scales relevant for pollutant transport through the atmosphere, and thus air quality management, has also changed. Initially, air pollution was conceived as a localized phenomenon and air pollution control efforts were focused on the urban scale. The resolution of urban "smoke" problems, as well as the gradual demographic changes toward more regional development (itself driven in part by urban air pollution), made air

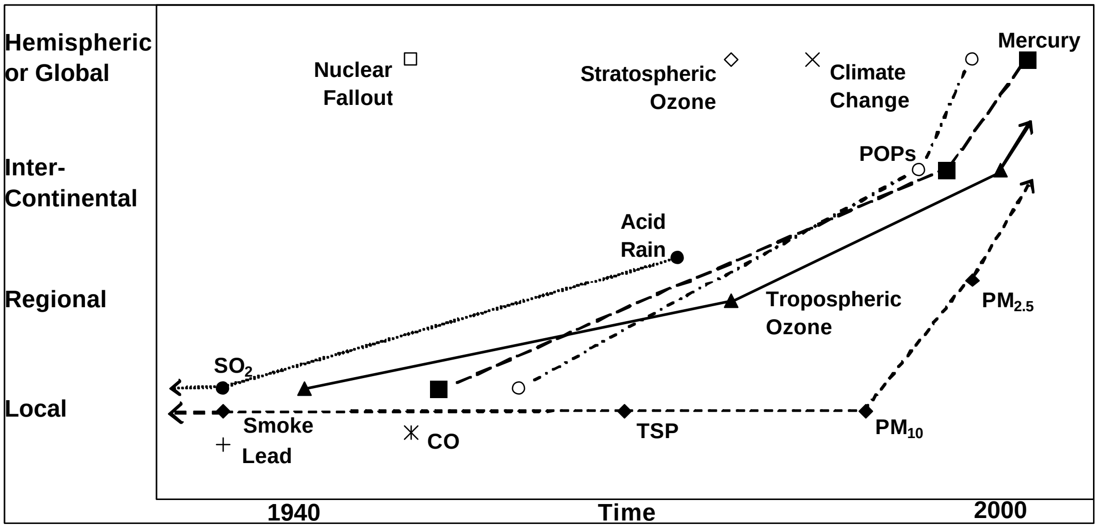

Figure 1 – Evolution of the perceived spatial scale of air pollution problems in the United States. Points indicate approximately when scientific consensus emerged that public policy action should be considered. While some pollutants have always been conceived of as local problems, some pollutants like O_3 and particles (first TSP, then PM_{10}, and then $PM_{2.5}$) have been reassessed over time as relevant on larger spatial scales. Other problems were conceived of originally at broader scales, such as acid rain at the regional scale, and there are several problems that have always been viewed globally.

pollution more regional. In the 1970s and 1980s, the perceived spatial scale of air pollution changed remarkably through studies that revealed that acidifying deposition is strongly regional, and even international, with transport between the US and Canada and between the nations of Europe [5, 6]. The regional nature of ozone, which was originally understood as an urban problem beginning in the 1950s, became a focus of management efforts in the 1990s as downwind jurisdictions discovered that they could not attain ambient standards because of emissions in upwind jurisdictions [7]. As emphasis on particle control has shifted to fine particles, the spatial scale of management efforts has also shifted from the urban to regional scale.

While our understanding of the geographical scale of conventional air pollution has expanded over time, other atmospheric problems were conceived of, from their inception, as global problems. These include studies of the transport of radioactive particles, climate change, and stratospheric ozone depletion. Measurements of chlorofluorocarbons (CFCs) in remote regions demonstrated that transport of long-lived species occurs [8]. Studies of the effects of CFCs on stratospheric ozone put atmospheric transport in a clearly global and very-long-term perspective, and led to the Vienna Convention and the Montreal Protocol, one of the earliest and most successful global agreements managing the global atmospheric commons [9].

Recently, the understanding of the transport of conventional air pollutants on international and now intercontinental scales, has taken a major step forward through the scientific research described in this volume. Satellite imagery, as well as analysis of surface observations, has provided vivid illustrations of individual events in which Saharan dust is transported to the Caribbean and Asian dust is transported to western

North America. Analyses of the trends in ozone observed at remote sites have provided evidence of the hemispheric transport of ozone and the increasing hemispheric burden of ozone in the free troposphere [10].

This same evolution of the perceived spatial scale of air pollution has occurred concurrently in Europe, though with slightly different emphasis on different problems, such as the earlier recognition of acidifying deposition as a regional problem in Europe. Developing nations are observed to follow the same historical progression, but fall at different places along this path depending on the status of economic development and the severity of air pollution problems. While many developing nations are at the stage of controlling smoke and other urban pollution problems, as the United States was in the mid-1900s, they do so now with a more complete understanding of the picture painted in Figure 1, and of the relative priorities and complex relationships between air pollution problems.

2.2 The Tightening Vise of Air Pollution Management

Four current pressures create a "tightening vise" that is increasingly faced by air pollution managers in industrialized nations. First, air pollution management has historically emphasized the control of local sources of pollution, with a relative lack of control of regional sources. Through time, this has led regional and international sources to contribute proportionally more to air pollution problems. Consequently, there has been an increasing emphasis on the control of pollutants that are transported over longer distances, as air quality managers look to force upwind jurisdictions to control their share of emissions. This same trend is now extending to the intercontinental transport of pollution.

Second, having already exhausted the cheapest and easiest controls, further local emissions reductions come at increasingly higher economic and political marginal costs relative to controls in upwind areas, although in some cases technological innovation may reduce the actual control cost.

Third, while the cost of local control is increasing, air quality standards have become more stringent, reflecting an increased environmental awareness and improved understanding of health effects. This third pressure is manifested in the new ambient standards for ozone and fine particles in North America and for ozone in Europe.

The fourth pressure arises from the rate and spatial pattern of global development, which is causing emissions of air pollutants and their precursors to increase most rapidly in the developing nations of Asia, Africa and Latin America. In addition to industrial emissions, often from inefficient and uncontrolled processes, emissions from biomass burning and windblown dust (caused in part by human contributions to desertification) also contribute, sometimes dramatically, to international pollutant transport.

The net result is that the regional or global background contribution to pollutant concentrations is growing, while standards are becoming increasingly stringent and local pollution controls are becoming increasingly expensive and difficult to achieve (see

Figure 2). Thus, air pollution managers are increasingly in a “tightening vise” of pressures from the industrialized world and growing emissions from the developing world. These pressures create an increased motivation for industrialized nations to help decrease emissions overseas. These foreign emissions, however, not only derive from different sources, but their management involves a very different set of actors with different priorities and technical and regulatory capabilities.

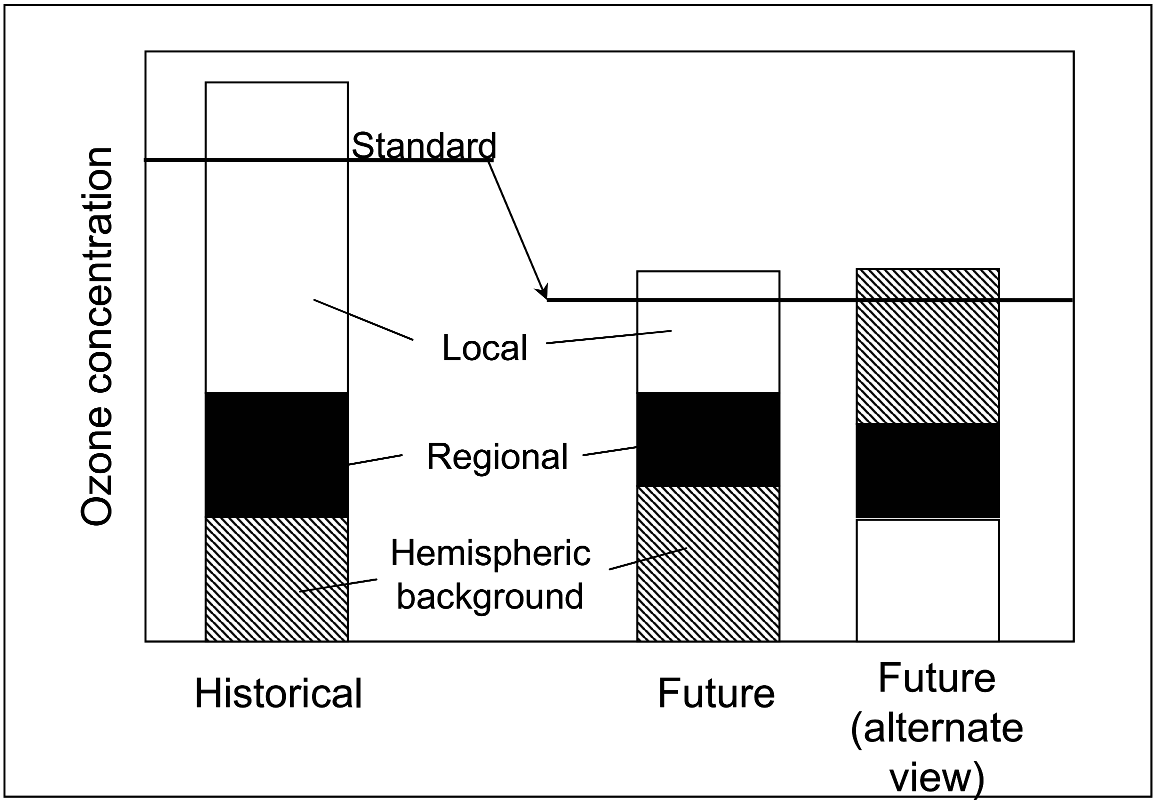

Figure 2 – The “tightening vise” of air pollution management, shown here (schematically) for ozone from the perspective of an industrialized nation. From the historical view to the future, air pollution managers succeed in reducing their local contribution to ozone, and work regionally with other jurisdictions to reduce the regional contribution. But the hemispheric background increases, while their air quality standard becomes more stringent. In the alternate view of the future, the hemispheric background, not the local pollution, pushes ozone above the standard, and the local air quality authorities blame other nations for their exceedance of the standard.

2.3 Overlapping Problems, Multi-Pollutant Strategies and Co-Benefits

Figure 1 suggests that the scope of air pollution concerns on the local, regional, and global scales is complex, and that the relative importance of different problems varies with spatial scale. These concerns are also interrelated to a significant degree. One example is that emissions of SO_2 contribute to fine particle formation on a local and regional scale, contribute to acid deposition regionally, and influence the global climate.

As discussed in other chapters of this book, the nature of intercontinental pollutant transport is different for different pollutants, although many management concepts are common. In most cases, intercontinental transport contributes only a fraction of the pollution at a given location, with the remainder coming from local or regional sources, as portrayed in Figure 2. For ozone and mercury, the contribution of intercontinental transport occurs mainly through the build-up of concentrations in the free troposphere on a hemispheric scale. For fine particles, on the other hand, transport during discrete meteorological events may be more important. For ozone and mercury, therefore, emissions throughout the hemisphere may be important; while for fine particles, there is a more clear direction of flow from source continents to receptor continents. Interestingly, the emissions that one would choose to control can differ depending on the scale of influence one cares about. For ozone, controls on emissions of VOCs will reduce local concentrations, while NO_X controls are likely to have more regional benefits [3]. For the global background of ozone, however, recent modeling results suggest that controlling emissions of methane in addition to NO_X will be most effective, while changes in emissions of VOCs are less relevant [11].

There are also close linkages between air pollution – especially the long-range transport of air pollution – and climate change. Ozone is a GHG, and fine particles also influence climate by altering the Earth's radiation budget regionally to cause a net cooling or warming [12]. The linkage to the long-range transport of pollutants is particularly important because urban-scale pollution occurs over too small a scale to have a meaningful influence on the global climate. In the case of particles, there has been recent interest in controlling emissions of black carbon, both because of its benefits for human health and as a way of more quickly reducing human contributions to climate change [13].

In addition to the many scientific linkages between air pollution and climate, important policy linkages result from the fact that many air pollutants and GHGs share common sources. Many actions to address emissions of some pollutants may also affect emissions of other pollutants, such as the effect of GHG mitigation on aerosol concentrations and climate [14, 15]. Likewise, there has been increased recognition of the "co-benefits" of GHG mitigation in terms of reduced air pollution [16, 17], and studies to plan the control of GHGs and air pollutants simultaneously [18].

Together, understanding of these scientific and policy linkages has led to an acknowledgment of a complex pollution control landscape, where there are multiple sources of pollution, causing emissions of multiple pollutants, in turn causing multiple impacts that become manifest in inter-related ways on local, regional, and global scales. Likewise, policy linkages extend to other goals, such as providing transportation and energy, which can overlap with environmental goals. Interest in multi-pollutant strategies comes not only from governments, which want more efficient policies, but also from industry, which wants to have more long-term certainty in regulations to aid business planning.

Given this complex landscape, the main question for air quality managers in industrialized nations becomes increasingly: How to plan local air quality management strategies, accounting for international pollutant transport, together with climate change and other economic and social priorities at the same time? Meanwhile, air quality managers will increasingly be inclined to pursue emissions controls overseas, where those emissions controls will be tied together with overlapping environmental and development priorities.

3 Status of Current International Air Pollution Control Regimes

To effectively manage the international or intercontinental aspects of air pollution, some form of an international regime is necessary. International regimes that address transboundary air pollution can be found at the binational, regional, and global scales. Some existing regimes are listed chronologically in Table 1.

At the binational level, existing regimes include cooperative agreements between neighboring nations, which identify joint goals and obligations, such as the Canada-U.S. Air Quality Agreement [29] or the La Paz Agreement between Mexico and the U.S. [30]. Binational regimes may also take the form of technical cooperation between more distant nations, such as existing cooperative agreements between the U.S. and China [31] or between Norway and Poland [32].

At the regional level, examples of existing multinational regimes range from initial agreements acknowledging shared interests, such as the Malé Declaration; to regional scientific cooperation, such as the East Asia Network (EANET) and the Arctic Council's Arctic Monitoring and Assessment Program (AMAP); and well-developed policy regimes, such as the Convention on Long-Range Transboundary Air Pollution (LRTAP Convention). Signed in 1979 and encompassing the United States, Canada, and all the nations of Europe, the LRTAP Convention is one of the most successful international environmental regimes. Over time, it has developed a robust analytical support structure that includes a number of working groups, task forces, and international cooperative programs, including the Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollution in Europe (EMEP). Eight protocols have been negotiated under the LRTAP Convention addressing financing of scientific cooperation and obligations to reduce emissions related to acidification, ozone, POPs, heavy metals, and eutrophication.

At the global level, existing regimes range from technical cooperation under the auspices of multinational organizations, such as the United Nations Environment Program (UNEP) and the Organization for Economic Cooperation and Development (OECD), to multilateral treaties, such as Vienna Convention and Montreal Protocol for the protection of stratospheric ozone, the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, and the Stockholm Convention on Persistent Organic Pollutants.

Table 1. Some International Agreements Addressing Transboundary Air Pollution

Agreement	Geographic Region	Pollutants Addressed	Reference
1979 Convention on Long-Range Transboundary Air Pollution (LRTAP)	United States, Canada, and 47 European Nations		[19]
1984 Geneva Protocol on Long-Term Financing of the Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollution in Europe (EMEP)			
1985 Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes By At Least 30 Per Cent (1st Sulphur)		SO_2	
1988 Sophia Protocol Concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes (NO_X)		NO_X	
1991 Geneva Protocol Concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes (VOC)		VOCs, O_3	
1994 Oslo Protocol on Further Reduction of Sulphur Emissions (2nd Sulphur)		SO_2	
1998 Aarhus Protocol on Persistent Organic Pollutants (POPs)		15 POPs	
1998 Aarhus Protocol on Heavy Metals (Metals)		Hg, Pb, Cd	
1999 Gothenburg Protocol to Abate Acidification, Eutrophication, and Ground-level Ozone (Multi-Effects)		SO_2, NO_X, VOCs, NH_3, O_3	
1985 Vienna Convention on the Protection of the Ozone Layer	Global (185 Ratifications)		[20]
1987 Montreal Protocol on Substances that Deplete the Ozone Layer		CFCs, and other O_3 depleting substances	
1992 United Nations Framework Convention on Climate Change (UNFCCC)	Global (188 Ratifications)	GHGs	[21]
1997 Kyoto Protocol			
1995 ASEAN Cooperation Plan on Transbounary Pollution	10 Southeast Asian Nations		
2002 ASEAN Agreement on Transboundary Haze Pollution		Visibility, Fine Particles	[22]
1996 Arctic Council	8 Arctic Nations	POPs, Metals	[23]
1998 East Asia Network	12 East Asian Nations	SO_2, Acidification	[24]
1998 Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia	8 nations on the Indian subcontinent		[25]
1998 Harare Resolution on the Prevention and Control of Regional Air Pollution in Southern Africa and its likely Transboundary Effects	Southern Africa Nations (3 primary participants)		[26]
2001 Stockholm Convention on Persistent Organic Pollutants (POPs)	Global (151 Signatories)	12 POPs	[27]
2003 UNEP Global Mercury Assessment	Global	Hg	[28]

While these existing regimes provide possible foundations for building future regimes to address intercontinental transport, additional institutional infrastructure will be required. Not all regions of the world are engaged in an international environmental policy regime that has the potential to address transboundary flows of air pollution, and some existing regimes are only in the early stages of development. Intercontinental pollutant transport can occur on spatial scales that exceed those of existing regional air pollution regimes. But given differences in the transport characteristics of pollutants, not all intercontinental pollutants may be appropriate to address through global regimes. Before discussing what future regimes may be most appropriate, we first consider how international regimes are constructed and what characteristics lead to their success.

4 Constructing and Implementing International Regimes for Air Pollution

The development of an international environmental policy regime is a social process, and like the process of developing scientific knowledge, this process takes time. Each of the regimes identified in the previous section or in Table 1 are at different stages of development. These and other international environmental policy regimes have developed through what has been called the co-production of science and policy [33]. Co-production is the idea that knowledge and political order are constructed, through social processes, in ways that enable each to support the legitimacy of the other. For example, government decision-makers support scientific research that they believe will help them structure policy options. Scientists focus their research to provide information that they believe will be of most use to the decision-makers. The research results, along with other considerations, constrain the policy options to be considered by the decision-makers. Once a policy framework is constructed, future research is focused to provide further information that is useful within this framework.

Studies of the development of international regimes suggest co-production does not usually follow a linear path of problem recognition leading to a search for solutions and then a policy choice among those solutions. From their comparative history of social responses to climate change, stratospheric ozone depletion, and acid rain, Clark et al. [34] suggest that the development of international regimes can be described in terms of separate streams of activity related to six management functions: risk assessment, monitoring, option assessment, goal and strategy formation, strategy implementation, and evaluation. The six streams of activity progress simultaneously, feeding each other. Each of the streams of activity may involve significant international cooperation. Periodically, the streams intersect where activities are brought together by conferences, assessments, or decision processes. The evolution of a social or policy response to a given issue through these six streams of activity may take long periods of time, even decades.

> "Our research has shown that the process of building capacity to address global environmental risks needs time. This is irreducibly true, since it is not primarily the amount of resources (human resources and money) that is of importance but rather the generation of the coordination, cooperation, and trust needed to create an effective management process." [34 p. 191]

During this slow evolution, attention to the issue by the public and decision-makers will rise and fall. It is helpful to know where one is in the cycle of waxing and waning public attention to constructively move the process towards a policy response [35].

While the development of international regimes may not follow a linear pattern, based on the literature on international environmental policy regimes, we have divided the development of regimes into two phases [36-38]. The first phase, which we will call the framing phase, focuses on organizing knowledge and politics around an issue and building new institutions. Policies developed during this phase tend to be "least common denominator" agreements that codify pre-existing positions, often those that already exist in national laws. The second phase, the implementation phase, focuses on the implementation of environmental policies and making further improvements in environmental quality. Policies developed during the second phase may be more complex, building upon continued technical cooperation and advancing common environmental goals. Some of the issues that arise in each of these two phases are discussed below.

4.1 Framing Phase

The initial phase of regime development involves building new institutions for collective action and focuses on bounding the issues under consideration and constructing conceptual problem frames. International environmental policy problems are often very complex, involving interrelated environmental phenomena and multiple human actors with multiple interests. Problem frames serve to simplify and make tractable the complexity of a problem that is the subject of scientific study, assessment, or policy debate. Like a camera lens, a problem frame not only defines the field of view, but also defines how the components of the system within the field of view and the relationships between the components are perceived [39]. Problem frames define what sorts of knowledge are relevant, and the appropriate data and analytical methods to use in gaining such knowledge [34]. In this way, a problem frame "provides us with a whole structure by integrating interests, values, actions, theory, and facts [40]."

Problem frames are socially constructed and reflect the beliefs of the participants in the process. Some beliefs, such as those related to national sovereignty, regional identity, and notions of rights and responsibilities, may be deeply held. These core beliefs evolve gradually [41], thus constructing a common problem frame between multiple participants may take a very long time.

An important step in developing a common problem frame is coming to a shared understanding of the nature of the physical systems involved. Many international environmental policy regimes have begun by creating institutions for cooperative scientific efforts. The LRTAP Convention grew out of cooperative studies of acidifying deposition in Europe initially organized by the Nordic Council and later by the OECD. This cooperation created the foundation for the formation of EMEP and the LRTAP Convention. The development of EANET has followed a similar path, beginning with cooperative scientific studies initially organized and funded by Japan, and now organized under the UNEP Regional Cooperative Centre in Thailand. In both of these cases, scientific cooperation was organized first by the downwind nations who were the recipients of transboundary flows of pollution. Once established, the coordination function was shifted to a more neutral international organization. Scientific studies conducted by individual nations that have clear environmental, economic, or political interests at stake may be perceived to be biased. The participation of representatives of different nations with different interests lends credibility to the results. Through international scientific cooperation, participants may not only develop a shared understanding of a problem, but they may also come to a new understanding of their own nations' self interests as they relate to that problem. Furthermore, cooperation on scientific studies helps to build relationships, goodwill, and trust, which can be carried into discussions of policy options.

A shared understanding of the physical problem to be addressed, however, does not have to come through participation in cooperative scientific research. In some cases, international regimes have formed due to events or scientific discoveries that have focused public attention on a particular environmental phenomenon. For example, the discovery of the stratospheric ozone hole in the 1980s spurred political action that resulted in the Vienna Convention and Montreal Protocol and the Indonesian fires of 1998 led to the ASEAN Agreement on Transboundary Haze Pollution. The signatories of the Malé Declaration in 2002 were informed by the findings of the Indian Ocean Experiment (INDOEX), an international scientific field study in which few of the Malé Declaration signatories were active participants [42].

In addition to a shared understanding of the physical systems to be addressed, it is important for the participants in an international regime to have a common understanding of the social, economic, and political implications of the environmental problem and its possible solutions. Managing transboundary air pollution can be complex because the polluter and the receptor are in different nations, which may have different legal and social norms concerning rights and responsibilities related to pollution. Some nations value a right to a clean environment; others value a right to use the environment's waste assimilative capacity. The relative priority of these rights may differ depending on whether the nation is the source or the receptor of the pollution. Some nations may see the international or global fraction of their pollution as "background," uncontrollable by domestic management; while others may blame the international contribution for pushing their air quality above the policy objective (see Figure 2).

Issues of rights and responsibilities are further complicated by differences in the wealth of the source and receptor nations. Developing nations may assert a right to exploit an equal share of the global commons or a right to follow a path of development and pollution similar to that of industrialized nations. Global policy agreements, such as the Stockholm Convention or Montreal Protocol, have included provisions for allowances, compensation, or assistance for less developed nations.

The more similar nations' interests or situations are to begin with, the easier it is to construct a common understanding. Thus, regional agreements between nations that share common borders, are interconnected politically and economically, or have additional reasons to cooperate other than air pollution, are generally easier to reach than global agreements, which involve a larger diversity of perspectives and positions. Given their relative tractability, regional agreements can serve as stepping stones to more comprehensive global agreements. For example, international control of POPs began with technical work under OECD that led to a regional agreement under the LRTAP Convention and then to a global agreement under the Stockholm Convention [43].

In many cases, upwind nations may have little reason to participate in an international regime, at least in terms of protecting their own environment. However, many other types of issues may bring them into the regime. Developing nations may participate as a way to secure development assistance. Nations may participate to protect or pursue interests related to economic trade or to establish relationships that are useful in addressing other concerns, such as national security. The early years of the LRTAP Convention were shaped in part by Cold War politics and were a mechanism of détente between the U.S. and its Western European allies and the Soviet Bloc [44]. More recently, participation in the LRTAP Convention has been shaped by the expansion and evolution of the European Union [45].

Coming to a common problem frame may take a long time. In some cases, agreement on some contentious elements of a frame may never be reached, and the regime either breaks down or continues in a fashion that accommodates different perspectives. However, once a viable problem frame and sustainable institutions have been constructed, the international regime can move beyond an acknowledgement of a problem and the need to work together and make progress towards environmental protection.

4.2 Implementation Phase

As an international environmental regime matures, it moves from the framing phase into the implementation phase, which builds on the institutions created in the framing phase and focuses on making increasingly substantive agreements and actions possible [38]. In this phase, participants begin to focus less on the international nature of the problem and more on identifying the most efficient solutions to the environmental problem, irrespective of national borders. Several of the regimes identified in Section 2 have reached this stage of development, such as the Montreal Protocol and the LRTAP Convention. The evolution of the LRTAP Convention is manifest in its protocols. The first generation of protocols, which includes the protocols of 1984, 1985, 1988, 1991, and 1998, primarily identified problems, established cooperation, and set readily attainable goals. The transition from the framing phase to the implementation phase coincided with the beginning of a second generation of protocols, including the 1994 and 1999 protocols, which established differentiated obligations based in part on analysis of environmental impacts.

While the implementation phases of mature regimes have included obligations or actions for environmental protection, sometimes with increasing stringency over time, it is legitimate to question whether the environmental protection associated with international agreements would have occurred without the regimes. In their review of international environmental policy regimes, Victor et al. find that almost all nations comply with almost all of their binding international commitments [46]. Given that governments often cannot ensure national compliance with environmental quality goals, it is not very surprising to find that most governments are very conservative in choosing what commitments to make. Therefore, they may not go beyond environmental protection efforts that have already been incorporated into their national laws. This suggests that compliance with international obligations and effectiveness in advancing environmental protection may not be the same; "compliance often simply reflects that countries can negotiate and join agreements with which they know they can comply [46]."

Although the direct effect of international regimes on environmental protection is difficult to establish in many cases, there are several ways in which participation in an international regime can affect national or local environmental policies and environmental quality. First, Victor et al. [46] note that, while national environmental protection efforts are often developed in response to key events or disasters or changing economic conditions, the existence of international regimes increases the impact of these events and enables policy advocates to seize the opportunities presented. The creation and shaping of environmental regimes is one of the few things that advocates can influence directly, unlike chance (and often unfortunate) events that can initiate major changes in policy. Second, participation in an international regime, especially those involving scientific cooperation, can change a government's perception of its own national interests, leading to a change in national policies [37]. As Young observes, "regimes are often effective in solving international problems when they can redirect the interplay of political forces within the domestic policymaking arenas of key members [1]." Third, as noted in Section 3.1, nations may agree to environmental protection efforts in return for action on another issue affecting their perceived self interests [47]. Finally, international regimes create a sense of peer pressure among nations. In his study of the LRTAP Convention, Marc Levy labeled this aspect of international regimes "tote-board diplomacy:" leading nations declare their intent to take strong environmental protection efforts, creating a challenge or pressure for other nations to follow [44].

4.3 Characteristics of Successful International Regimes

A number of scholars have identified characteristics of international regimes that contribute to their effectiveness in maintaining international dialogue and cooperation and, ultimately, in influencing policies at the national and international level. These characteristics include:

- **Sponsorship:** Effective regimes, at least in the beginning, need to have strong sponsorship from one or more nation whose interests are served by investing the resources needed to establish and maintain new institutions. Over time, other nations may share the burden as they see the value of participating in the regime, but the major sponsors can have a lasting influence on the framing of issues, the nature of institutions, and the eventual policy outcomes [48].
- **Participation:** In the short term, regimes with few and homogeneous participants tend to be more effective than regimes with many and heterogeneous participants. However, in the long term, it is unlikely that regimes that do not include all major contributors to the problem can remain effective [46]. Furthermore, national

governments must be sufficiently concerned about the problem to actively participate and cooperate. To help raise government concern, effective regimes can create, collect and disseminate technical knowledge; link environmental issues to other issues that governments are more directly concerned about; and help magnify public pressure, both domestic and international [37].

- **Coordination:** Effective regimes have the capacity to coordinate efforts of the participants, often through central secretariats or administrators. Financially strong and technically capable secretariats tend to make regimes more effective and can be "critically important in a situation where several or all the cooperative parties have weak domestic administrative capacities [49]."
- **Technical Capacity:** Effective regimes have the ability to generate and use technical analyses that are credible and relevant to all of the participants [34, 49]. Establishing credibility and relevancy in technical analyses requires transparency, participation, and a level of technical capability within each of the participating nations [50]. Effective regimes can help build national capacity by creating professional networks and providing financial assistance to aid in the transfer of technical and management expertise [37]. Furthermore, effective regimes create institutions to actively inform policy makers of the results of scientific research and technical analyses, through assessments, reports, and meetings.
- **Adaptability:** Effective regimes have sufficiently comprehensive and flexible agendas and structures that allow them to adapt to changing knowledge, conditions, and needs [7]. Flexibility can allow the parties within the regime to take advantage of windows of opportunity to make progress on specific issues when they open [34, 49].
- **Trust:** Effective regimes require multiple layers of trust between the parties [34, 50]. At the individual level, trust is developed through repeated interactions of individuals in both formal and informal settings, provided by hierarchies of workgroups, taskforces, and committees [50]. At the institutional level, trust is associated with decision-making processes that are fair, provide adequate time for participation, and include opportunities to revisit the decision, in another venue or subsequent negotiation [43, 50]. Furthermore, the regime must provide a positive contractual environment, in which the costs of acquiring information and iterative bargaining are minimized and parties are held accountable for fulfilling their commitments [37]. This accountability may be achieved through reporting systems and implementation review bodies [49].

It is important for an international environmental policy regime to develop these characteristics if the regime is to evolve beyond the framing phase and into the implementation phase.

5 Prospects for Future Regimes

Given our understanding of how international environmental regimes evolve and what characteristics contribute to their success, what can we say about the likely success of regimes for addressing intercontinental transport? What actions in the short term should be recommended to develop or strengthen regimes?

There are several possible levels at which governments can address intercontinental transport, including actions taken unilaterally, bilaterally, or multilaterally on regional, hemispheric, or global scales. Actions at these different scales, however, are not equally likely to be successful in the short and long term.

5.1 National and Bilateral

At the national level, nations have incentives to reduce their own emissions, to the extent they will benefit from decreased air pollution within their own borders. The incentive to reduce emissions to address intercontinental transport is currently weakest among the developing nations, where emissions are growing rapidly. In many developing nations, awareness of environmental quality is growing, but these nations may lack the technical expertise to understand the sources and effects of air pollution, and may lack the regulatory capabilities and experience to effectively control the sources. Lacking this expertise, developing nations will not only have reduced capabilities to address their own air quality problems, but will be less likely to participate meaningfully in international regimes addressing transboundary air pollution.

Even where scientific, technical, and managerial expertise exists in industrialized nations, transferring this expertise to developing nations can be expensive, but ultimately worthwhile. Given the importance of developing nations' emissions for existing and projected intercontinental transport problems, it is implausible that international regimes to address intercontinental transport will be effective without first taking steps to build capacity in developing nations to understand and manage air pollution. Capacity-building actions should, therefore, be a short-term priority for any series of actions to address intercontinental transport. Such capacity-building, whether undertaken bilaterally with individual developing nations or multilaterally through regional or global regimes, need only focus on providing support for developing nations to address their own air pollution problems. Industrialized nations will benefit from such pollution control efforts through reduced international or intercontinental transport, and through the other benefits that motivate development support currently.

Unilateral actions by industrialized nations to improve scientific understanding of pollutant transport are important, but sponsorship of cooperative actions to develop a shared understanding can produce greater international legitimacy and can better support international agreements.

5.2 Regional

Regional regimes have proven effective at reducing international pollution among neighboring countries, and regional regimes are growing among developing nations. Although current regional regimes do not cover the geographic scope of intercontinental transport, they offer existing functional structures that can serve as a basis for further cooperation with other nations and regimes. Regional regimes have the advantage of dealing with nations that are often similar in development characteristics and have shared regional interests, which as discussed previously, is a common characteristic of successful regimes.

Because of the scale of transport, regional regimes are most likely to be effective for fine particle pollution and acid deposition, but will not be able to cover all relevant source nations for ozone, mercury, and POPs. In North America and Europe, regional agreements focusing on the control of NO_X as a regional precursor to ozone are already in place. With respect to fine particles, regional regimes should work within their boundaries to confront the causes of widespread particulate emissions from windblown dust, exacerbated by desertification, and forest fires, as well as the important industrial and urban sources of particles. Given the health effects associated with fine particles, investment in capacity building activities related to fine particle control is likely to be very beneficial.

The LRTAP Convention, which has a geographical scope stretching from North America, across Europe, and into Central Asia, provides an existing forum where meaningful progress can be made towards addressing the intercontinental transport of multiple pollutants. It is also a framework through which capacity-building activities engaging developing nations can be further encouraged. Likewise, the inception of regional pollution regimes in Asia and Africa, with a foundation in developing a shared scientific understanding of air pollution problems, is encouraging and should be supported by industrialized nations.

As pressure mounts to address intercontinental transport over larger spatial scales, there will be pressures for regional regimes to expand their boundaries, or to work together with regimes representing other regions. Both should be encouraged, as regional agreements provide useful existing structures.

In addition, environmental managers increasingly use market-based mechanisms, such as emissions trading, to reduce overall control costs. The potential for cost savings has motivated discussion of emissions trading under the Kyoto Protocol, but agreeing upon the rules for international trading has proved contentious. Trading in GHG emissions, which are long-lived and relatively homogeneous, is relatively simple compared to trading pollutants that are more heterogeneous and have strong local or regional components, such as fine particles, ozone, mercury, and POPs. Any trading system for these pollutants would have to be designed to take source-receptor relationships into account and avoid the creation of emissions hot spots.

5.3 Hemispheric and Global

Regimes on a hemispheric or global scale are the only regimes that can fully address some problems of intercontinental transport. This observation has led some scholars to speculate about the potential for a new hemispheric treaty on air pollution [51]. Hemispheric and global regimes, however, lose some of the characteristics that make regimes successful. At this scale, the commonalities of interests, shared borders, and regional objectives that support the development of regimes are weaker, while inequities between industrialized and developing nations are highlighted.

While developing nations have shown a great willingness to participate in global environmental regimes, they are less frequently willing and able to participate at the level of reducing their own emissions. Although the Montreal Protocol is a very successful global regime, for example, some developing nations still produce CFCs. Likewise, no binding emissions reduction commitments for developing nations are currently contemplated under the UNFCCC. The prospect of using a global regime to leverage meaningful emissions reductions from developing nations, therefore, is not likely to be successful in the short-term unless significant incentives are made for developing nations to participate. Incentives in the form of development aid for clean energy infrastructure can advance the developmental and environmental priorities of both developing and developed nations.

A global regime currently exists for POPs and has momentum to address this problem globally for several important pollutants. For mercury, a global regime has recently been created to focus on scientific assessment and capacity building. Given that scientific understanding of mercury transport is weak in relation to other pollutants, scientific cooperation is important at this stage. Beyond an assessment, actions in industrialized nations to control their own emissions, and capacity-building and financial support for projects that reduce mercury emissions in developing nations will be important.

No global regime exists for ozone or other traditional air pollutants. The creation of such regimes may be part of a long-term solution for these problems, but it is not clear how these regimes might evolve. Under the UNFCCC, significant actions may be taken to address emissions of the precursors of ozone and fine particles, since both affect climate change. Methane emissions are already addressed by the UNFCCC, and their control will benefit climate change efforts as well as air quality management efforts.

As mentioned earlier, however, achieving agreement among many parties in a global regime can be time-consuming. We therefore are not optimistic that global regimes can bring meaningful emissions reductions in the short term, and should therefore not take priority over the types of bilateral and regional activities discussed earlier.

6 Needs for Research to Support an Effective Policy Response

The air pollution and atmospheric science research community can contribute to the development of effective regimes to address intercontinental transport by focusing their research on meeting the information needs of policy makers and by helping to effectively communicate their research results to inform policy decisions. Before discussing some specific information needs of policy makers, we briefly discuss scientific assessment processes. In recent decades, assessments have served an increasingly important role in summarizing scientific knowledge and in communicating that understanding to decision-makers – so much so that assessments are now routine parts of domestic and international environmental management [34, 52, 53].

6.1 Assessment Processes

Although assessments are often organized around the production of a report or book, it is more useful to view scientific assessments of environmental problems as communication processes [54]. This view of assessments stresses the social processes by which expert knowledge is organized, evaluated, integrated, and presented to inform decision-making, with communication occurring both among scientists and between scientists and policy-makers. Indeed, a major function of assessments is to allow an extended technical dialogue to occur among experts united by discipline or topic area, but differentiated by nationality or other interest.

Participants in assessments, as well as most scientists conducting the research that may be used in assessments, generally want their efforts to increase knowledge and improve environmental policy [55, 56]. Decision-makers in business and government want their decisions to be firmly grounded in scientifically-supported data and analysis so that they improve environmental quality [57, 58]. In part, this desire reflects a belief that scientific and engineering research produces knowledge more likely to be effective than personal opinion, political ideology, or other sources of information. Decision-makers therefore use assessments to show that policy positions are not merely a pursuit of self-interest, but are informed by objective analysis to achieve agreed upon public ends [59].

Experience with past assessments has made clear that assessments that effectively inform decisions have several common characteristics:

- **salience** - the assessments address questions that are relevant for decision-making and are made available in a timely fashion, ahead of critical decision junctures
- **legitimacy** - the assessments are developed through a fair and transparent process in which relevant perspectives are represented
- **scientific and technical credibility** - the individuals, methods, and institutions that are engaged in the assessment are judged to be competent and appropriate [54].

To increase salience and legitimacy, participants in assessment processes have increasingly engaged decision-makers early in the process to provide input on relevant questions [60].

6.2 Information Needs

6.2.1 Source-Receptor Relationships

Since intercontinental transport involves contributions of many source nations influencing many receptor nations, developing fair and effective policies will require scientific tools capable of determining contributions at the level of individual nations. Current global chemical transport models (CTMs), however, involve large uncertainties in quantifying source-receptor relationships, especially at the national or sub-national scales. An ambitious scientific research program, addressing both physical and chemical processes, is needed over the coming decades to better characterize and quantify transport in CTMs without excessive computational burdens.

Atmospheric science on the global scale is an "observation-limited" science, where a lack of ambient observations, particularly in remote regions and above the surface, limits progress in quantification. In the coming decades, it will be necessary to design measurement campaigns so that they will be useful in evaluating global models and to increasingly use automation to collect and analyze air quality samples for multiple pollutants. Satellite-based instruments are especially promising because of their ability to provide global, long-term monitoring.

Emission inventories used as input to CTMs are themselves highly uncertain, especially in developing nations, and efforts need to be made around the globe to create accurate, gridded emissions inventories. Likewise, the development of ground-based air pollution monitoring networks in developing nations will help improve CTM capabilities. More importantly, developing better emissions inventory and ambient monitoring capabilities is critical for improving the air quality management in developing nations. Such capacity-building steps are among the most important actions that industrialized nations can take in the short term.

CTMs need not only to reproduce current air quality and transport, but also to simulate well the changes in air quality due to future changes in emissions and meteorology. Since climate change will be one of the key atmospheric changes over the next century and since ozone and fine particles are also key uncertainties for predicting global climate change, it is important to increasingly coordinate efforts with the climate research community and to represent climate change and relevant climate-air pollution feedback processes in CTMs.

6.2.2 Control Technologies and Costs

An important question that will drive the policy debate in industrialized nations is: To meet domestic air quality goals, is it more cost-effective to reduce emissions abroad or domestically? Even though the impact of one ton of emissions from abroad may be less than the impact of a domestic ton, a one-ton reduction abroad may be substantially less costly. In some cases, the emissions to control abroad may be different than the relevant domestic emissions – for ozone, it is most important to reduce domestic emissions of VOC or NO_X, while controlling foreign emissions of methane may be more important. If it is shown that the cost-effectiveness, expressed as cost per unit reduction in domestic concentration, is comparable for domestic and international controls, then the motivation for investment in international controls will increase substantially.

For this purpose, research into control costs in developing nations is clearly important. Since many industrial and vehicular sources are similar, emissions reduction strategies for developing nations can learn directly from past actions in industrialized nations. Other sources in developing nations, however, will require new research to develop effective control technologies and determine control costs for sources such as fires and household energy uses. Working together with developing nations to develop control technologies and management strategies, industrialized nations can help improve developing nations air quality management capabilities and bring multiple economic and environmental benefits.

6.2.3 Integrated Tools and Future Scenarios

To inform policy decisions, analytical tools are needed to combine information from modeling studies of source-receptor relationships with information on the costs of pollutant control in different nations. Such tools may use the output of global CTMs in a reduced form, for easy combination with other global, regional, and local models of energy, economics, emissions, and pollution transport. As an example, the RAINS models for Europe and Asia use reduced-form transfer matrices derived from atmospheric models to represent source-receptor relationships for a number of regional pollutants [61, 62]. Such integrated tools should be used to explore the effects of future scenarios of growth and emissions, and to identify and highlight cost-effective strategies to achieve environmental objectives across multiple spatial scales.

Given that some emission control actions may reduce several pollutants simultaneously, integrated analysis tools should be developed to integrate information across different air pollution problems, such as ozone, fine particles, mercury and POPs, and to explore the various linkages between climate change and air pollution policies. Some integrated assessment programs have recently taken such steps, such as the inclusion of greenhouse gas emissions in the RAINS project [63], and efforts to add regional pollutants to climate integrated assessments [64].

Finally, it is important to use these tools for long-term planning of air quality, climate, and energy policies that will achieve environmental, economic, and developmental objectives. This can be done by considering a variety of future development and emissions scenarios over the next 20 to 100 years, to identify policies that are robust over a variety of plausible futures.

7 Next Steps

While further research and better information is needed, a better understanding of intercontinental air pollution transport will not be enough to address the problem. New or expanded international regimes are needed, but the development of effective regimes takes a great deal of effort and time. Given that not all efforts are equally likely to be successful, efforts to further develop regimes at all scales should be encouraged, with different results expected at each scale. While global regimes may ultimately be necessary to address global scale problems, these regimes will be the most difficult to establish. Global regimes have the inherent difficulty of dealing with many parties and highlight differences between industrialized and developing nations, particularly where industrialized nations are downwind of developing nations. Existing regional regimes provide useful foundations upon which additional cooperation could be constructed, and creative uses of these regimes should be encouraged to address transport over larger scales.

Any of these efforts will require national leaders to recognize the need to cooperate and to commit the resources, particularly from industrialized nations, necessary to improve our understanding of the problems and build institutions. In the short-term, the most important investments are those that build capacity in developing nations for quantifying and managing their own air pollution problems – such investments will have the desired effects of decreasing emissions and transport, and will prepare developing nations to more meaningfully participate in international regimes.

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