Current Status and Future Potential of the Multi-pollutant Approach to Air Pollution Control in Japan, China, and South Korea

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I. Introduction

1. Purpose of this study

Air pollution is now high on the policy agenda in East Asia following severe air pollution episodes in late 2012 and early 2013. The Chinese government has been adopted various domestic measures to strengthen air pollution control, and the State Council highlighted 10 of these measures in June 2013. Concerns regarding air pollution have been raised in neighboring countries as well and interest in international cooperation is growing. For example, the governments of China, Japan, and South Korea recently agreed to strengthen cooperation on air pollution at the Tripartite Environment Ministers Meeting (TEMM) among the three countries in May 2013 after recent severe air pollution episodes in China attracted global attention. Article 8 of the TEMM Joint Communiqué declares that the ministers agreed to "newly establish the Tripartite Policy Dialogue on Air Pollution for exchanging information on related policies, technologies for monitoring, prevention and control technologies, research, capacity building and international cooperation, and for consideration of future cooperation."[1] While this cooperation could take many forms, one possible element could be to adopt a multi-pollutant multi-effect (MPME) approach (Suzuki (2013).

The purpose of this study is to assess the extent to which selected East Asian countries are already adopting a multi-pollutant multi-effect (MPME) approach to air pollution control or certain key aspects of it, and what would be required to further promote implementation of this approach. In doing so, this study will clarify the different elements of a MPME approach and compare the extent to which case study countries have adopted these different components. Finally, it will consider how strengthened international cooperation might facilitate more advanced implementation of a MPME approach in East Asia.

The MPME approach is considered necessary in order to deal with an increasing number of pollutants, the complexity of their interactions, and the growing importance of secondary pollutants which are formed these complex interactions. A firm

[1] Joint Communiqué, The 15th Tripartite Environment Ministers Meeting Among Japan, Korea and China, May 5-6, 2013, Kitakyushu, Japan <http://www.temm.org/sub03/11.jsp?commid=TEMM15> (accessed on 29 July).

understanding of these interactions is increasingly necessary to secure the effectiveness of air pollution control policies, since the composition of complex air pollution varies significantly both within and between countries. The MPME approach is based on scientific assessment of the complex interaction among pollutants as well as their complex effects on human health and ecosystems, so it enables a more holistic and integrated approach. This is not only more effective, but it also increases the cost effectiveness of reduction measures. The traditional approach of addressing each air pollutant individually is less effective and more costly. A certain level of research capability is necessary in order to conduct these analyses, and is an important foundation for the MPME approach.

One of the leading examples of the MPME approach is the Convention on Long-range Transboundary Air Pollution (LRTAP) centered in Europe. LRTAP has been considered to be a reasonably successful framework for air pollution control, and Agenda 21 states that “[Europe’s] experience needs to be shared with other regions of the world” (Takahashi 2000).

Since East Asia is suffering from increasingly severe air pollution which is also becoming more transboundary in nature, experts and policymakers have considered whether LRTAP might also serve as a model for East Asia, although there are few studies explicitly addressing this question. Of course the nature of air pollution problems in East Asia and Europe are very different, as are the relevant political, economic, social, and geographic conditions. Yet, it is possible that certain elements of the LRTAP approach may be useful for East Asia, even if they are not packaged together into a complex, legally binding treaty. Therefore, this paper will not take up the overall question of whether the LRTAP framework could be applied to East Asia. Instead, it will start by identifying one of the key features of LRTAP – the MPME approach – which was originally employed in the Gothenburg Protocol adopted in 1999 (Simpson and Eliassen 1999), and examine the extent to which selected key countries are already adopting certain elements of this approach.

One of the main objectives of this paper is to clarify the different conceptions and elements of the MPME approach. The LRTAP approach is a commonly accepted version, but the concept is understood in different ways by different studies and in different countries. Moreover, when the domestic air pollution policy frameworks of non-LRTAP countries are analyzed to assess the extent to which they are following an

LRTAP-style MPME approach, it becomes readily apparent that there are several stages even of the LRTAP type MPME approach. In particular, it seems useful to distinguish between the multi-pollutant and multi-effect aspects.

This paper finds that key East Asian countries, including China, are already starting to shift away from single pollutant approaches. These new approaches have been described in various ways, and they have not been specifically labeled as an MPME approach. However, a close examination of these policies and related policy discussions indicates that the case study countries are considering or implementing certain aspects of the MPME approach. China, in particular, is on the road to developing a domestic LRTAP-type MPME framework to address domestic transboundary air pollution between provinces in the long term. This further suggests that an LRTAP approach might be implemented domestically by individual countries in stages without the need for a legally binding agreement. International cooperation would still be helpful to coordinate common methodologies and promote the development of related implementation capacity.

This paper focuses mostly on the multi-pollutant aspects, although it addresses multi-effects aspects to some extent. There are two reasons for this. First, a multi-pollutant approach is the first priority since it is a prerequisite for a multi-effects approach. Second, the policy trends in the three case study countries are mostly related to the multi-pollutant aspect, although the three cases have also made significant progress in developing research capability related to multi-effects.

2. Overview of the status of Air Pollution in East Asia and need for a multi-pollutant approach

In the 1990s, Asia surpassed North America and Europe in terms of nitrogen oxide emissions (Akimoto 2003). As the Asian economies have grown, emissions of air pollutants from the region have also grown rapidly. A recent study by the Clean Air Initiative for Asian Cities (CAI-Asia) Center (2012), based on the air quality data for 234 Asian cities[2], indicated that, while some improvements in air quality have been achieved in nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) levels, levels of particulate matter with a diameter of 10 micrometers or less (PM_{10}) and SO_2 continue to exceed World Health Organization (WHO) air quality guidelines (AQG). The report also

[2] This does not include data from Japanese cities.

identified that there is not enough air quality data to assess particulate matter with a diameter of 2.5 micrometers or less ($PM_{2.5}$) and ozone.

Asian countries have made efforts to protect public health from the adverse effects of air pollution through various policy measures including setting ambient air quality standards, and adopting emission controls on both stationary sources and mobile sources. The major targets of those efforts have been primary pollutants, which are directly emitted from a source in to the atmosphere such as sulphur oxides (SO_X), nitrogen oxides (NO_X), and carbon monoxide (CO) (UNECE 2010).

While the efforts to reduce the primary pollutants have led to some improvements, the current status of the concentrations of secondary pollutants such as ozone and PM remain unsolved or even getting worse in East Asia. The severity of such pollution is increasing in China, and excessive high concentration incidents of $PM_{2.5}$ have "generated public outcry and many citizens are urging the government to adopt the new legislation" (Meng 2013). However, the air quality data on ozone and PM2.5 is still at an early stage of development and there is not enough data for analysis (Clean Air Initiative for Asian Cities (CAI-Asia) Center 2012). Emissions that affect ozone and PM concentrations in the atmosphere are SO_2, NO_X, non-methane volatile organic compounds (NMVOC), ammonia (NH_3), methane (CH_4), organic carbon (OC), black carbon (BC) and CO.

Therefore, to tackle the emerging secondary pollutant issues, policy measures encompassing multiple-pollutants are imperative. In addition the multi-effects approach is also becoming more important as it becomes clear that multiple pollutants have multiple effects on human health as well as various aspects of the environment. Linkages between air pollution and climate change are also becoming more important. Adoption of a more comprehensive MPME approach, combining both multiple pollutants and multiple effects, will be necessary to increase the cost effectiveness of reduction measures. These issues are further complicated by scientific evidence of the long range transport of those secondary pollutants (UNECE 2010), underlining the desirability of strengthened international cooperation.

3. Research Questions and Structure

Thus, this report addresses the following questions:

1) What are the main components of a multi-pollutant multi-effect approach? To what extent are case study countries already pursuing multi-pollutant and multi-effect approaches?

2) What kinds of capacities or institutions or administrative mechanisms are necessary to implementing multi-pollutant multi-effect approaches in countries? Which ones are currently used, and what kind of gaps exist?

3) What needs to be done (or can be done) from the perspective of international cooperation in implementing multi-pollutant multi-effect approaches?

Following this introduction, Section 2 reviews the concept of multi-pollutant multi-effect approach and classifies the main elements of the concept to enable a rough comparison of the case study countries in terms of the extent to which they are adopting some elements of this approach. Sections 3 to 5 present case studies from a few Asian countries to identify their current status in terms of the MPME perspective, and they draw policy implications for the future application of multi-pollutant approach to the air quality policy. The final chapter provides a comparative analysis of the case studies and discusses the possible ways forward for air quality policies in Asia not only from the viewpoint of domestic policies but also from the perspective of international cooperation.

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II. Concepts and Classification of Multi-pollutant and Multi-effect Approaches

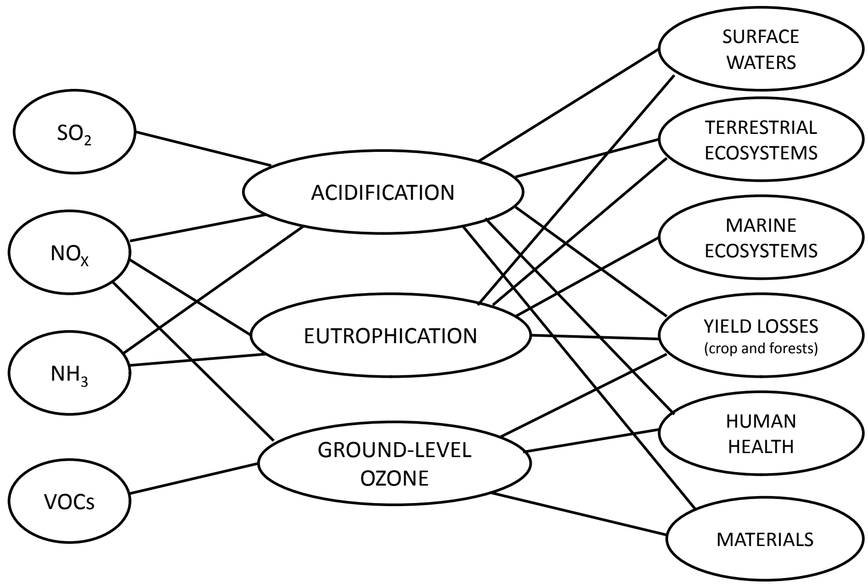
1. The Concept of MPME

There are numerous natural science based studies developing various models to analyze the interactions between multiple air pollutants as well as multiple effects. These studies may occasionally make specific policy recommendations based on the results (e.g. for stricter standards). However, they generally do not address the MPME approach as a coherent, systematic approach to influence policy, or its explicit incorporation into a domestic policy or international treaty structure.

Much of the discussion from the policy perspective comes from two sources, discussions and explanations of LRTAP's Gothenburg Protocol, and discussions around USEPA's efforts to promote a similar system in the US. Discussions of the Gothenburg Protocol generally consider MPME as an integrated system and it is closely associated with the legally binding LRTAP treaty. The USEPA uses a different terminology, calling it a multi-pollutant approach, although its long run intention seems to be similar to LRTAP's MPME approach including multi-effects. The term "multi-pollutant" approach rather than MPME is used by a recent academic study, although multi-effects are incorporated in the authors' concept, and it appears to focus more on the scientific analysis rather than classifying actual policy systems. (Hidy 2011). This section will infer the key elements of the MPME approach by directly analyzing the components of the Goethenburg Protocol as well as discussions around USEPA's efforts in the US.

2. The Gothenburg Protocol

On 30 November 1999, in Gothenburg, a protocol was adopted within the framework of the LRTAP, which employs "new and innovative multi-pollutant and multi-effects". In contrast to earlier LRTAP protocols, which targeted a single substance (e.g., SO_2) or one main environmental effect (e.g., acidification) at a time, the 1999 Gothenburg Protocol targets four substances (multi-pollutants) —NO_X , volatile organic compounds (VOCs), SO_2, NH3)— and three effects (multi-effects) acidification, tropospheric ozone formation, and eutrophication (Wettestad 2002). The Protocol, aiming to abate the specified multi-effects, sets emission ceilings to be met by the year 2010 for the four pollutants. Those ceilings are mandatory and differ from country to country. The commitment of each country was decided through negotiation strongly guided by the results of an integrated assessment model, which estimated the emission reductions required of each country based on information regarding impacts on ecosystems, deposition patterns, and abatement costs. The concept map of the multi-pollutant multi-effect approach in the LRTAP is shown in Figure 1. (Secretariat for the Convention on Long-range Transboundary Air Pollution 1999, revised 2002).



（Source: Secretariat for the Convention on Long-range Transboundary Air Pollution 1999, revised 2002）

Figure 1.1 Concept map of the multi-effect and multi-pollutant approach in the Gothenburg Protocol of LRTAP

The MPME approach of LRTAP's Gothenburg Protocol is considered to be the first major case of its implementation in a legally binding international treaty (Sliggers and Kakebeeke 2004). It is has two main dimensions. First, it is a system of scientific analysis which assesses the interactions among pollutants as well as their effects. Second, this scientific system is integrated into the Protocol's implementation framework, essentially as a policy. There are five main components as follows.

a. Multiple pollutants. The LRTAP members originally chose four pollutants. It was considered important to consider them together, because their interactions were important to addressing the targeted effects.

b. Multiple effects. The goal of the LRTAP members was to address three main effects, which in turn impacted various ecosystems, crop yields, materials, and human health.
c. Models to calculate the interactions among pollutants, as well as their effects.
d. Models to calculate the most cost effective ways to meet the targets.
e. Scientific analysis and models contributed to setting the emission ceilings.

These components are not just a system of scientific analysis, but they are also fully integrated into the Protocol and its implementation structure, as the designated pollutants and effects are continually monitored and modeled by implementing bodies. Modeling of the transboundary flows of air pollution contributed to setting the reduction targets, which were finally determined by political negotiations, and the targets were legally binding, but these aspects of LRTAP are analytically separate from the MPME aspect.

It is also important to emphasize that MPME analysis is necessary to optimize the effectiveness and costs of reduction strategies. It can more accurately determine acceptable levels of pollution for human and environmental health, help to evaluate pollution management priorities, help to balance between environmental and human health priorities and other tradeoffs.

The scope of the MPME approach of the Gothenburg Protocol is considered to be quite broad. Nevertheless, it is by no means comprehensive. After the Gothenburg Protocol, it was decided to extend the multi-pollutant, multi-effect approach further and try to link the transboundary air pollution problem with the health risks of air pollution at the local level (Sliggers and Kakebeeke, 2004). In 2012, following years of wide-ranging and intense negotiations, the parties agreed to amend Gothenburg Protocol to include emission reduction commitments for fine particulate matter (PM) for the first time.

3. United States

While LRTAP developed its secondary pollutant protocols alongside the development of an MPME approach, the United States already established reduction goals and strategies for complex chemicals like Ozone and PM2.5 before an MPME approach was articulated. The National Ambient Air Quality Standard (NAAQS) is the national regulatory framework for air pollution control in the United States and limits for Ozone, NO2, and Sulfur were set simultaneously in 1971. While NAAQS determines air quality standards, planning and implementation of reduction strategies are delegated to state governments. The implication of this division for management of a secondary pollutant like Ozone is that the national framework only minimally acknowledges the significance of primary pollutants when calculating secondary pollutant reduction goals. The Ozone NAAQS contains minimal discussion of VOCs or NOx so the root cause of Ozone production and reduction is lacking in focus (2009). Conversely the NOx NAAQS only evaluates the inherent toxicity of NO2 and its role in O3 formation is not discussed. Finally, the simultaneous evaluation of pollutant goals is hindered because the NAAQS review process accommodates one pollutant per year. This precludes any evaluation of synergies between pollutant combinations (Hidy 2011).

While this division of responsibility and top-down delegation of ambient standards has resulted in administrative rigidity in the United States, the relative autonomy of state and municipal authorities in carrying out State Implementation Plans (SIPs) allows for reduction goals beyond those mandated by the federal government, an encouragement of cost effective solutions, and the freedom to implement novel reduction strategies such as MPME.[3] Autonomy of reduction strategies at the state level is advantageous because comprehensive and effective management of secondary pollutants often requires a localized strategy.

The US Environmental Protection Agency has tried to consider how the MPME approach could be implemented in the US since the 1990s. Since the Clean Air Act Amendments of 1990, the traditional approach has been one pollutant at a time (USEPA 2008) although multiple pollutants were covered. In 2004 National Academy of Sciences (2004) called for “modifying current air quality management practices to integrate assessment, planning, and implementation efforts across all air quality and environmental issues—that is, a multi-pollutant (and multimedia) focus” (USEPA 2008). Napolitano, et. al. (2009) describe a series of unsuccessful efforts to develop a multi-pollutant approach for the electric power sector by Congress from the 1990s, and the EPA’s regulatory efforts in the 2000s, which were overturned by the courts; the

[3] For an example, see New York State Department of Environmental Conservation, Division of Air Resources, (2009). A Conceptual Model for the Development of An Air Quality Management Plan for the State of New York. D. o. A. Resources; Wesson, K., et al. (2010). "A Multi-pollutant, risk-based approach to air quality management: Case study for Detroit." Atmospheric Pollution Research: 296-304; and New York State Energy Research and Development Authority, (2012). Applying the Multi-Pollutant Policy Analysis Framework to New York: An Integrated Approach to Future Air Quality Planning. Albany, NY.

article tries to persuade stakeholders that a multipollutant approach will be more cost effective.

Although the USEPA uses the term “multi-pollutant” approach, rather than the term MPME, it is clear that the USEPA’s approach includes both multi-pollutant and multi-effects aspects. USEPA’s efforts to develop this approach include both modeling development and pilot projects in various cities such as Detroit (USEPA 2008). Thus, the US is currently developing the scientific analytical capability for an MPME approach, and it is in the process of integrating it into domestic air pollution policies, but this process still appears to be in relatively early stages.

4. Synthesis Definition and Application to Policy

Among the varying definitions, a common theme is an understanding of interactions between anthropogenic pollutants in the atmosphere and their effects on human health and ecosystems. Even if modelling and reductions strategies exist for several different pollutants individually, they may not necessarily be integrated in an MPME approach without equal consideration of the interactions and synergies between pollutants. The extent to which it is actually used in policy decisions varies, as does the scope of pollutants and effects covered, and the depth and sophistication of the scientific analysis.

Now it becomes clear that countries or groups of countries considering whether to adopt this approach can choose to select only certain components, or they may modify the components; it is not necessary to adopt the entire system all at once. First, countries may begin with scientific studies and developing models first, before integrating them into a domestic policy or international treaty framework. Second, alternatively, countries without sufficient scientific capability may adopt a policy system based on a scientific MPME framework (or parts of such a framework) developed elsewhere. Third, countries might select different pollutants. Fourth, countries might focus on different effects. Fourth, countries might use a variety of models, or again, instead of developing their own models, they may directly adopt a MPME-based policy system (or parts of it) developed elsewhere. Fifth, countries might introduce the MPME approach in a stepwise manner, rather than all at once, starting with a subset of pollutants, application to a specific industrial sector, or pilot areas such as a cities or subregions.

Finally, multi-pollutant and multi-effect aspects are analytically separate, and countries may adopt aspects of the multi-pollutant approach before progressing on the multi-effects aspects. In particular, countries may integrate multi-pollutant aspects into actual policy before relying on multi-effect types of analysis, and governments may support multi-effect research capability before integrating it into the policymaking process. A more detailed classification of the different elements of multi-pollutant and multi-effect approaches is made in the next section.

5. Phases of Transition

The transition from a single pollutant control approach to a multipollutant approach is summarized in a four step process which is presented below in Table 1.1. The transition from a single-effect approach to a multi-effect approach in the LRTAP example is illustrated in Table 1.2 and the combination of multi-pollutant and multi-effect phases are compared in Table 1.3. This can be considered to illustrate a possible pathway to a more comprehensive and unified MPME approach.

5.1. Transition from a Single Pollutant to a Multi-pollutant Approach

Single Pollutant Control Phase 1 – Managing Direct Toxicants and Simple Secondary Pollutants Individually

Domestic air pollution regimes typically began with a focus on primary pollutants with direct negative effects on environment or health. These pollutants known as direct toxicants include NO2, Sulfur, VOC, Heavy Metals, and Hazardous Pollutants (HAPs)[4]. Slightly more complicated are secondary pollutants formed from only one anthropogenic precursor. These include NOx or SOx in the formation of acid deposition.

Single Pollutant Control Phase 2 – Managing Complex Secondary Pollutants Through One Primary Pollutant

Secondary pollutants including Ozone and PM2.5 are more complicated to control because they are formed from multiple anthropogenic precursors. Management frameworks historically begin addressing the problem partially through single pollutant management of the precursors (Hidy 2011). LRTAP's VOC Protocol (1991) took this

4 Examples include the London Smog and regulations of criteria air pollutants in the United States.

approach for ozone management by focusing on VOC control. Reductions in one primary pollutant are not coordinated with the others. Japan's recent VOC reductions for the purpose of Ozone control also follow this approach.

Multipollutant Control Phase 1 – Managing a Secondary Pollutant through Multiple Primary Pollutants

Effective control of secondary pollutants with multiple anthropogenic precursors such as Ozone and PM2.5 requires a significant increase in understanding of atmospheric chemistry and adjustment of administrative capacity to identify and compare multiple scenarios for abatement. In this phase, reduction of a secondary pollutant is dealt with comprehensively by controlling the corresponding primary pollutants.

The 1991 VOC Protocol acknowledged the limitations of a single pollutant approach to Ozone control by mandating later negotiations to incorporate NOx and VOC simultaneously in Article 2.6 (LRTAP VOC, 1991 Article 2.6). Article 2.6 provided a formal basis for the simultaneous evaluation of NOx and VOC in what became the Gothenburg Protocol.[5] While the prioritization of Ozone showed that a single pollutant approach was inadequate, it also led to a new policy framework to address multiple effects because its primary pollutant NOx is also a component of acidification. NOx was first addressed by LRTAP in the 1988 protocol to abate acidification. A subsequent revision expanded the protocol to incorporate critical levels for ozone as well as eutrophication (Sliggers and Kakebeeke 2004). The Gothenburg Protocol was therefore expanded to incorporate the already existing multi-effect framework. The inertia of MPME resulted in inclusion of sulfur for acidification and Amonia (NH3) (Sliggers and Kakebeeke 2004). It is clear from this development that the challenge of managing Ozone as a secondary pollutant with multiple anthropogenic precursors initiated an MPME framework. The multi-pollutant and multi-effect approaches were merged in the Gothenburg Protocol.

Phase 1 control of PM2.5 requires a complex understanding of the pollutant's regional specificity. As this mixture pollutant can have variable composition, a detailed analysis of the prominent primary pollutants and the photochemical interactions that lead to the specific mixture must be well documented. Korea is an example where much of this

[5] The text of the Gothenburg Protocol is available at http://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/1999%20Multi.e.pdf (accessed July 30, 2013).

preliminary knowledge is understood leaving much potential for comprehensive implementation of MPME.

Multipollutant Control Phase 2 -- Managing Multiple Secondary Pollutants and Toxicants In an Integrated Way

In this phase, reductions in all designated secondary pollutants as well as direct toxicants are planned simultaneously. Adequate comparison between different control strategies must be conducted without constraint to a particular outcome (Hiddy, 2011). While an Integrated Assessment Model can synthesize the diverse scientific knowledge needed to form policy decisions, iterative discussions are necessary between policy makers and scientific communities to compare geographically specific priorities and political realities with multiple reduction scenarios (Sliggers and Kakebeeke 2004).

Nevertheless, while the Gothenburg Protocol was a major advance compared to the LRTAP VOC Protocol, it still did not cover all air pollutants comprehensively. It was not until the Gothenburg Revision of 2007 that the more variable secondary particulate matter (PM2.5) was addressed. The possibility of including greenhouse gasses was also discussed, but these are still not incorporated into the Gothenburg Protocol.

Table 1.1 Transition from a Single Pollutant to a Multi-pollutant Approach

Control Strategy		Description	Example
Single Pollutant Control	Phase 1	Managing one or more primary pollutants individually	Direct Toxicants (NO2, Sulfur, VOC, Heavy Metals), precursors for simple secondary pollutuants (Nox and Sulfur for acid control)
	Phase 2	Managing complex secondary pollutants through one primary pollutant	VOC or Nox for Ozone control
Multi Pollutant Control	Phase 1	Managing a secondary pollutant through multiple primary pollutants	VOC and Nox for Ozone control, Sulfur for PM2.5 control
	Phase 2	Managing multiple secondary pollutants and toxicants in an integrated way	Simultaneous Ozone and PM management

5.2. Transition from Single Effects to Multiple Effects

The transition from a single-effect to a multi-effect approach is mainly related to the desirability of addressing multiple negative impacts of air pollution, including various health and environmental impacts, and the fact that individual pollutants may have more than one kind of negative impact.

It is very important to note that movement towards a multi-effect approach requires significant advances in scientific capacity, since combining the analysis of interactions between pollutants with analysis of multiple effects is highly complex. Moreover, analysis of the geographic movement of pollutants is also necessary to analyze multiple effects.

Example of the transition to multiple effects in the LRTAP Gothenburg Protocol

There are two other dimensions to the multi-effect aspect which are often discussed in terms of the Gothenburg Protocol. The first is the extent to which related scientific knowledge was actually incorporated into the policy and/or international agreement. The second is the type of reduction targets that can be supported by the scientific analysis. These aspects of LRTAP's transition are summarized in Table 1.2.

Table 1.2 Transition from Single Effects to Multiple Effects in LRTAP

Stages of Effects	Type of reduction strategy	Degree of importance/input into policy
Single Effects (Effects Supported)	Flat Rate	Limited (LRTAP 1985 Sulfur Protocol)
Transition from Single to Multiple Effects (Effect Based)	Critical Loads	Higher (LRTAP VOC Protocol 1991 & Sulfur Protocol Revision 1994)
Multiple effects	Risk-based (advanced)	Highest (Gothenburg Protocol 1999 & LRTAP NOX Revision)

The first phase of the single effect approach can be classified as effects supported. The state of scientific knowledge is sufficient to identify some cause-effect relationship, but it is not well developed enough to help create a detailed or geographically specific strategy. Therefore, in the case of the first Sulfur Protocol of 1985, the member countries agreed to equal or "flat rate" reductions.[6] The role of science in setting the targets was limited.

The second phase can be described as effects supported. In this phase, the level of scientific capability is higher, and it can play a more direct role in supporting the policy. In the case of LRTAP, it led to the critical load approach. It could be used to analyze

6 The text of the protocol, "Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on the Reduction of Sulphur Emissions or Their Transboundary Fluxes By at Least 30 Per Cent," is available at http://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/1985.Sulphur.e.pdf (accessed July 30, 2013)

single or multiple effects. By the next Sulfur Protocol of 1994, it was economically unfeasible to require flat rate reductions and politically unviable to suggest reduction goals without a firm scientific basis. This transition from “effects-supported” to “effects-based” was predicated on establishing quantitative values for establishing an acceptable level of pollution. These values, referred to as “critical loads” for ecosystems and “critical levels” for human health (both will hereby be referred to as critical loads), vary depending on the specificity of the region and are therefore reliant on geographically referenced data. In the case of LRTAP, critical loads were synthesized with emissions inventories, dispersal models, and reductions technology data in the Task Force on Integrated Assessment Model to create multiple reduction scenarios. These were presented to the Working Group on Strategies and were gradually refined through an iterative discussion with the taskforce (Sliggers and Kakebeeke 2004). In the case of LRTAP this meant that an effects-based strategy yielded different reduction goals for each country based on the integrity and pollution tolerance of the effected ecosystem. The 1994 Sulfur Protocol was the first instance of an effects-based reduction strategy (Sliggers and Kakebeeke 2004).

The third phase, multiple effects, requires an even higher degree of scientific and modeling capability to analyse the multiple effects of multiple pollutants. The Gothenburg Protocol is considered the first example of this stage. The scientific analysis played a major role in the overall structure and direction of the protocol. Although in the end, the actual targets were decided based on political considerations, the use of differentiated targets as well as the final target values were strongly informed by the scientific analysis. Recent advanced science is moving in the direction of a more risk based methodology for setting targets, but a critical load approach may also be used with a multi-effect approach.

5.3. Combination of multi-pollutant and multi-effect aspects

The incorporation of interlinkages between greenhouse gasses and air pollutants, including air pollution’s effects on climate change as well as climate change’s amplification of pollution effects is a further step that can be incorporated in an MPME approach. This would require a combination of both multi-pollutant and multi-effect aspects.

Table 1.3 below illustrates how different phases of single/multiple effects progressed with the transition to a multi-pollutant approach in LRTAP. It shows that in LRTAP, the advancement of the multi-pollutant aspect generally progressed along with the transition to multi-effects. The table also illustrates the possibility to add greenhouse gasses to the list of designated pollutants, thereby expanding the multi-pollutant approach, as well as moving to a risk-based approach for addressing effects, which has not yet been adopted by LRTAP.

Table 1.3 Progression of MPME Implementation in LRTAP

Y axis denotes coverage of pollutants while X denotes the range of effects

	Pollutant Control	Effects Supported	Effect Based	Mult Effects Based	Climate	Risk Based
S1	1 Direct Toxicant or acid component	LRTAP Sulfur Protocol (1985)	LRTAP Sulfur Revision (1994)			
S2	1 O3 or PM component		LRTAP VOC Protocol (1991)	LRTAP NOX Revision		
M1	2 O3 or PM component			Gothenburg Protocol (1999)		
M2	2+ O3, PM, Acid, component, Toxicant etc.					
Climate					Gothenburg Revision (2007)	

It is important to understand that the adoption of a multi-effect approach is analytically separate from how the extent to which the effects analysis (regardless of single or multiple effects) is used in the in the target setting process, or the nature of which targets are adopted. Countries could develop capabilities of multi-effect analysis without closely integrating it into the policymaking process. Likewise, a country could decide to incorporate multi-effect analysis into the policymaking process but use flat rate reduction targets or critical loads rather than a risk-based approach.

Countries without their own capability to conduct effects based analysis – regardless of single or multiple effects – may adopt generic standards (such as critical loads) based on such analysis recommended by organizations such as the United Nations World Health Organization or from critical levels established for unrelated geographic contexts. This may be adequate as a first step, but eventually analysis based on local conditions will be necessary in order to maximize the cost-effectiveness of reduction strategies.

6. Necessary Implementation Capacity

Based on the example of the Gothenburg Protocol, considerable implementation capacity is needed to implement the MPME approach, either as a system of scientific analysis and/or as a policy system. This includes both scientific/technical capacity as well as policy institutionalization.

Scientific capacity includes not only highly skilled human resources, but also the relevant scientific equipment and modeling capability. Monitoring and data are also essential. EU scientists developed this capability over many years, and it involves several research institutes and universities. Data collection is institutionalized through EMEP. Analysis of effects, particularly on human health and particularly in East Asia, are still not fully understood, and advanced research on these topics is underway in many areas. This kind of scientific capability is not easy for developed countries, and is quite challenging for developing countries, which may need more international assistance with capacity building.

The level of policy institutionalization is also high in the case of the Gothenburg protocol, with a legally binding treaty. LRTAP implementation is also supported by the EU, UNECE, as well as the member countries' domestic legal frameworks. This level of institutionalization may be difficult to reproduce in other regions.

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III. Japan's VOC Emission Reduction Policy – Implications for the Multi-Pollutant Multi-Effect Approach

1. Introduction

Japan successfully reduced air pollutant emissions in the 1970s and 1980s, and has managed to keep the ambient air concentrations leveling off since then (OECD 2010). The emission reduction measures including ambient air pollution standards and emission standards were basically based on the single-pollutant approach, with the standards and targets basically set for individual pollutants.

A need to adopt a new approach to incorporate a multi-pollutant perspective in the air quality policy had not been widely recognized after the severe air pollution settled down, while experts in the area of air pollution started to feel the need to address the issue from multiple aspects. In the previous study by the author, one of the reasons identified for the little interest in a multi-pollutant approach was the lack of urgency to employ new policy approach in the air pollution control as Japan's regulations on individual air pollutants have been considerably successful (Matsumoto 2012).

Meanwhile, there seem to have emerged a new policy trend for a multi-pollutant approach in Japan, while not drawing so much public attention. An indicative change is the restructuring of the expert committees under the Central Environment Council. While the emission reduction of volatile organic compounds (VOCs) had been deliberated within the Expert Committee on VOCs under the Atmospheric Environment Committee, the VOC committee itself announced a recommendation to dissolve the Committee and set up a new committee to comprehensively examine policies related not only to VOCs but also to photochemical oxidants $PM_{2.5}$ (VOC Expert Committee 2012). One of the backgrounds of this recommendation was the extremely low attainment rate of EQS for photochemical oxidants (0% for the fiscal year 2010), regardless of the significant reduction attained in the VOC emission, a precursor of photochemical oxidants, from stationary sources.

This chapter focuses on the VOC emission reduction policy that seems to have played an important role in the transition from single-pollutant approaches to a multi-pollutant approach, and address the common research questions of this report, including: the extent Japan already pursuing multi-pollutant multi-effect approaches; institutions that are necessary to implementing multi-pollutant multi-effect approaches in Japan; and the current status of such institutions and existing gaps.

2. Air pollution control during 1960-1990s

Japan experienced severe air pollution during the era of the rapid economic growth. Problems related to human health and visibility became prominent and worse especially since late 1950s. In order to address the problems, the Japanese national government enacted the Air Pollution Control Law in 1968 and adopted various measures to reduce emissions from both stationary and mobile sources. First, the country established statutory ambient air environmental quality standards (EQS) for five major pollutants, namely, sulfur dioxide (SO_2), carbon monoxide (CO), suspended particulate matter (SPM)[7], nitrogen dioxide (NO_2) and photochemical oxidants. Second, stationary sources were addressed through regulatory measures including strict emission standards and total emission control programs launched for the specified areas with severe air pollution. Third, to reduce mobile sources in the major urban areas, the *Law Concerning Special Measures to Reduce the Total Amount of Nitrogen Oxides Emitted from Motor Vehicles in Specified Areas (Automobile NO_X Law)* was enacted in 1992. In 2001, by adding particulate matter (PM) as another regulated pollutant, a new law was established (*Law Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides and Particulate Matter*).

Local governments also played important roles in emissions reduction. *Pollution Control Agreements (kogai boshi kyotei),* launched during the era of severe industrial pollution, took the form of highly decentralized agreements between local authorities, private firms and local residents' groups. The local agreements often substantially preceded rather than complement national regulation both in terms of stringency levels and in types of pollution addressed (Tsutsumi 2001; Welch and Hibiki 2002). Local governments in the designated areas of the national laws also supported national efforts to curb emissions, such as the developing and implementing *Total Emission Reduction Plans* stipulated in the Automobile NO_X Law.

[7] SPM defined in the Japan's Basic Environment Law is particulate matter suspended in the atmosphere with a diameter of 10 micrometers or less.

As a result, the compliance rates of the ambient air EQS have improved considerably for SO_2, NO_2 and CO (OECD 2010). However, even in the early 2000s, the compliance rates of the EQSs for SPM and photochemical oxidants remained low. Regarding SPM, attainment rates of the EQS were 52.6% at ambient air pollution monitoring stations and 34.3% at roadside air pollution monitoring stations in the fiscal year (FY) 2002 (April 1, 2002 - March 31, 2003). As for photochemical oxidants, the frequency of photochemical oxidant warnings, which are issued when one-hour value of the concentration of photochemical oxidants is more than two times higher than the EQS and was forecasted to continue due to weather condition, increased over years and the total number of warnings during FY 2002 was 184 days in 23 different prefectures, which was still equivalent to the level of mid-1970s.[8]

Facing the stagnant high concentrations of SPM and photochemical oxidants, some policy changes took place. First, SPM was added as a pollutant regulated in the major urban areas which had been under the regulation by *Automobile* NO_X *Law*, and the law was replaced with a new law titled as the *Law Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides and Particulate Matter*).

Second, a policy to address VOC emissions from the stationary sources was adopted. VOCs are one of the substances affecting the formation of both SPM and photochemical oxidants. The precursors of the secondary particles of SPM include VOCs from factories and vehicles, SO_X and NO_X as well as biogenic VOCs and SO_X from volcanic activities. Photochemical oxidants are formed through photochemical responses between the VOCs and NO_X compounds in the atmosphere in the presence of sunlight (especially ultraviolet). In addition, VOCs are found to be involved in the formation of SPM from inorganic compounds such as SO_X and NO_X, through the formation mechanism of the photochemical oxidants.[9]

Despite the important roles that VOCs play in the formation of SPM and photochemical oxidants, Japan had not introduced VOC emission regulation except for the vehicle emission regulation on hydrocarbon and efforts by some pioneering local governments to regulate stationary sources from the perspective of photochemical oxidants reduction.

[8] Cabinet Decision on a Bill to Control the Emission of VOCs (MOEJ Press release) <http://www.env.go.jp/en/press/2004/0308a.html > (accessed 7 December 2012).
[9] Review Committee on VOC Emission Reduction (2003) Emission reduction of VOCs - results of a series of considerations.

3. VOC emission reduction policy

(1) Policy process

Under the circumstances described in the above, VOC emission reduction increasingly drew attention as a common precursor of SPM and photochemical oxidants. In February 2004, the Central Environment Council submitted to the MOEJ an opinion report on the emission control of VOCs.[10] The report warned of urgent need to address the serious ambient levels and health effect concerns related to SPM and photochemical oxidants, and thus emphasized the need to reduce the emissions of VOCs, which are precursors of SPM and photochemical oxidants, from the stationary sources in a comprehensive manner. It proposed a target to reduce VOC emissions from stationary sources by 30% by the FY 2010 compared to the emission level of FY 2000. It further recommended promoting effective emission reduction measures to address stationary VOC sources by combining both legal regulation and voluntary actions in an appropriate manner, calling it a “best mix.”

In accordance with the report, the Air Pollution Control Law was partially amended at the 159th Diet and was promulgated on 26 May. The amended law came into effect on 1 June 2005, while the provisions related to VOC emission regulations were decided to be enforced on 1 April 2006.

(2) Outline of the policy

The amended law incorporates the recommendations by the Central Environment Council. Major components of the amendment include: 1) targeting VOCs from the stationary sources as an effort to reduce SPM and ozone, 2) specific emission reduction target, and 3) policy mix of legal regulation and voluntary actions.

1) Targeted VOCs

The Article 2-4 of the Law defines VOCs as organic compounds which are emitted into the air or in gaseous form when dispersed excluding the substances which are not causing formation of SPM and oxidants. Eight substances were specified as “excluded”

[10] Original title in Japanese: Kihatsu sei yuuki kagobutsu (VOC) no haishutsu yokusei no arikatani tsuite.

by Cabinet Order and they include methane and chlorodifluoromethane.

2) VOC emission reduction target

The emission reduction target was set to be 30%, by the fiscal year 2010 compared to 2000, following the suggestion by the Central Environment Council.[11] The rationales for the target were the estimates based on a scientific simulation model. It was estimated that, a 30% reduction of VOCs would improve in the attainment rate of the SPM in the area under the regulation of the Automobile NO_X/PM Act, and increase the number of monitoring stations that do not exceed the warning level of photochemical oxidants up to 90 %.

3) Introduction of the “best mix” of the policy measures

The amendment was the first environmental legislation for the Japanese government to put the concept of “best mix” of policy measures into implementation. The best mix in the VOC emission reduction indicates an appropriate combination of legal emission controls and voluntary actions by business entities to reduce emissions and spread of VOC (Article 17-2).

The legal emission controls are applied only to large scale emitters of VOCs with potential emissions larger than 50 tons per year. The large scale VOC emitters are obliged to notify the prefectural governor of installation and change of the VOC emitting facilities, comply with the emission standards, and monitor VOC concentrations. The types of the regulated facilities include: painting facilities and drying facilities for painting; drying facilities for adhesives; drying facilities for photogravure or offset printing; drying facilities for production of chemical products; cleaning facilities for industrial production; and VOC storage tanks (Katsumata, 2008).

The emissions not subject to the above-mentioned legal regulations shall be reduced through voluntary actions. The measures to be taken under voluntary actions for VOC reduction were left to the discretion of business entities, while the government was expected to facilitate their voluntary actions through various measures.

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[11] Environmental Risk Countermeasures Joint Working Group of the Industrial Structure Council (First meeting) Document 5 “Framework of VOC emission reduction measures” (in Japanese), 1 June 2005.

(3) Policy outcome

This scheme resulted in the successful reduction of VOC emissions. The estimated VOC emission in fiscal year 2010 was 791,420 tons per year, while the emission in fiscal year 2000 was 1,416,812 tons per year. The reduction rate over the decade was 44.1%, which significantly exceeds the targeted 30% reduction.[12]

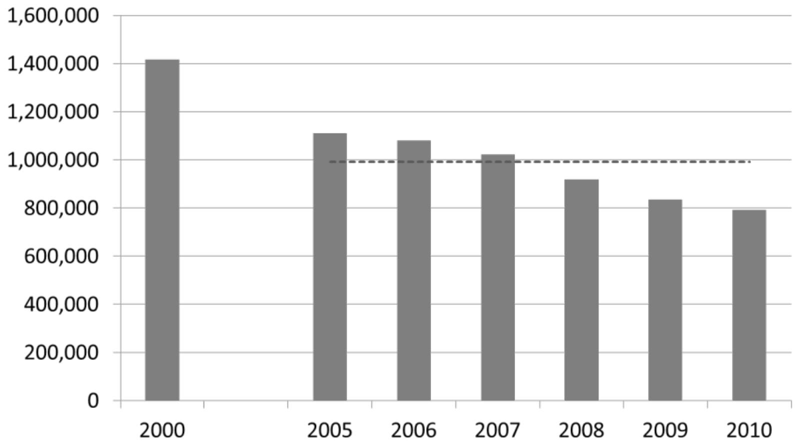

Figure 3.1 VOC emission (2000-2010)　(tonnes)

Accordingly, the concentrations of NMHC and 19 substances composing VOC, which are the precursors of SPM and photochemical oxidants, are found to be decreasing. Data also suggest that attainment rate of EQS for SPM improved to exceed the expected achievement (around 93%), although it should be noted that such improvement should not be attributed not only to the VOC reduction policy but also to the introduction of more stringent vehicle emission standards.[13]

However, the result regarding the effectiveness of the VOC reduction policy on the frequency of the photochemical oxidant warning was far from the ex-ante estimate, which expected the number of the monitors that do not exceed the warning level to

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12 Atmospheric Environment Committee of the Central Environment Council (35th), Document 3 “Emission inventory of VOC (revised version)” (in Japanese) , 9 September 2012.

13 VOC Expert Committee, Atmospheric Environment Committee of the Central Environment Council. Decepmer 2012. Future Emission Control Measures of Volatile Organic Componds (Report) [Kongo no kihatsu-sei yuki kagoubutsu (VOC) no haishutsu taisaku no arikatani tsuite (Hokoku)].

increase up to approximately 90%. A report submitted by the Study Committee on Photochemical Oxidant[14] shows that there is a gap between the ex-ante estimate and the ex-post monitoring of photochemical oxidants. The data shown in the report indicates that the rate of the monitors that did not exceed the warning level have been leveling off, while some improvements are suggested including declining trends of photochemical oxidant warning frequencies in Tokai and Kinki areas and reduced concentration in highly concentrated areas.

The causes of the gap between the current status of photochemical oxidant warnings and the ex-ante estimate have not been fully analyzed.[15] The Study Committee on Photochemical Oxidant's report points out possible reasons including naturally formulated VOCs (from vegetation), potential for ozone formation (MIR: Maximum Incremental Reactivity) differs among VOCs, area-specific conditions, and transboundary factors.

Thus, the VOC reduction policy achieved the numerical emission reduction target on the one hand. On the other hand, it fell short of the one of its major purposes, which is the improvement in the ambient concentration of photochemical oxidants.

4. Discussion

1) To what extent is Japan already pursuing multi-pollutant multi-effect approaches?

Following the category defined in Chapter 2, the Japanese policies related to air quality before the 2000s are found to fall into the category of the Single-Pollutant Control Phase 1. Ambient air quality standards were set for five individual pollutants (SO_2, CO, SPM, NO_2, and photochemical oxidants) separately, without fully considering the complex interactions among the pollutants in the atomosphere. Primary pollutants such as SO_X and NO_X were the major foci of the emission standards and total emission control programs for specific areas. Vehicle emission standards, which were tightened over years, were set individually for each pollutant: CO, HC, and NOx for

[14] Report submitted by the Study Committee on Photochemical Oxidant. March 2012.
[15] FY 2020 Report of the Working Group on the VOC Countermeasures for the Next Period. March 2011.

gasoline-fueled vehicles and CO, HC, NOx, PM, and black smoke for diesel-powered vehicles.

Categorizing the above mentioned VOC policy, which was adopted mid-2000s, is not straightforward and falls into the transitional period between two phases, that is, somewhere in between the Single-Pollutant Control Phase 2 and the Multi-pollutant Control Phase 2. In one sense, the Japan's VOC policy has commonality with the adoption of the LRTAP's VOC protocol in 1991, which is an example of the Single Pollutant Control Phase 2 in that both aimed to reduce ozone through VOC reduction. However, the scope of the Japan's VOC policy was not only limited to reduction of ozone but also to SPM. In other words, the amended Air Pollution Control Law adopted policies to address VOC as a common precursor of SPM and oxidants. Yet, the policy does not seem to have reached the stage to be categorised solely in the Multi-pollutant Control Phase 2 as the simulation study which was used as a ground for the emission reduction target did not fully consider the chemical interactions between ozone and $PM_{2.5}$.

A policy shift towards the more advanced level of the Multi-pollutant Control Phase 2 can be found in the deliberation of the follow-up scheme of the VOC reduction policy suggested by the VOC Expert Committee under the Central Environment Council in December 2012. In response to the consultation by the Minister of the Environment in April 2012, the Special Committee on the VOC Emission Reduction under the Air Environment Committee of the Central Environment Council was tasked to deliberate the follow-up scheme for VOC reduction after the target year of 2010. The Committee, while concluding that it is appropriate to continue the current emission reduction scheme, further proposed the dissolution of the VOC committee into a new committee to address not only VOC, but also photochemical oxidants and $PM_{2.5}$. Its rationales included the complex linkages among VOC, photochemical oxidants and $PM_{2.5}$, need for collecting information and data on VOC emission status as well as effectiveness in emission reduction, and necessity to further examine alleviation of burdens on the business.

With regards to the multi-effect aspect, that Japan's policies can be considered "effects-based" with special attention to health effects in setting EQS. Emission standards related to vehicle exhausts and SO_X/NO_X from stationary sources, on the other hand, had been set not directly related to such effects but more based on the available technology levels. The VOC reduction policy might be labeled as “multi-effect based” as the ultimate purpose was to reduce the effects related to both ground-level ozone and particulate matters.

2) What kinds of capacities or institutions or administrative mechanisms are necessary to implementing multi-pollutant multi-effect approaches in countries? Which ones are currently used, and what kind of gaps exist?

It would be necessary to build capacities to elucidate the complex chemical reaction leading to formulation of secondary pollutants such as ozone and PM as well as to clarify the health and ecological effects caused due to the co-existence of those pollutants in the atmosphere.

With respect to the formation mechanism of ozone, further studies are needed related to naturally formulated VOCs, potential for ozone formation differing among VOCs, area-specific conditions, and transboundary factors. To this end, it would be necessary to improve monitoring and conduct multifaceted analysis of data, to elaborate emission inventories, and to refine simulation models, as noted in the Report by the VOC Expert Committee. The formation mechanism of PM also needs further studies to be elucidated. In addition, the development of the nation-wide monitoring network that can measure the concentrations of $PM_{2.5}$ is still underway and behind schedule. MOEJ announced that there will be 556 monitoring stations of $PM_{2.5}$ by the end of March 2013, while the original target was 1300 stations by that time, due to the heavy financial burdens to local governments.[16] Another reason why the number of the monitoring stations of $PM_{2.5}$ is still limited is that Japan had not established the EQS on $PM_{2.5}$ until 2009.

To ensure and further facilitate multi-pollutant approach beyond the scope the ozone and $PM_{2.5}$ and realize the comprehensive management of air quality, it would be desirable to develop an integrated assessment system. This point was raised by some experts when the author conducted interviews regarding the views on the multi-pollutant approach (Matsumoto 2012). Challenges identified by the study related to introduction of a multi-pollutant approach included “comprehensive collection and analysis of environmental information", “development of an integrated assessment model and establishment of critical loads", and “estimation of health risks". In addition,

[16] Jiji Press, February 7 2013, Only 40% provide monitoring data, air pollution monitoring on $PM_{2.5}$ [Kansoku data teikyo 4 wari domari, PM2.5 no taiki osen kanshi de].

experts pointed out challenges related to build consensus with various stakeholders.

Japan has already launched some of the efforts towards multi-pollutant multi-effect approach. First, as a part of the VOC emission reduction policy, an emission inventory of VOCs has been developed by the MOEJ. Second, coordination is being launched among the different committees addressing different pollutants (VOC, ozone). Third, voluntary approach employed policy complementary used together with legal control to meet the top-down target as a part of the VOC, seems to have paved the way to facilitate the participation by small scale facilities which are difficult to address through regulation.

3) What needs to be done (or can be done) from the perspective of international cooperation in implementing multi-pollutant multi-effect approaches?

Considering increased attention to the secondary pollutants across the Asian region, the fact that formation mechanism of the secondary pollutants are still not fully elucidated, and rising concern over transboundary inflow, there is a need to conduct international collaborative research analyzing from the multi-pollutant and multi-effect perspective.

At the same time, under the urgent severe pollution situation, some actions to collaborate to reduce emissions need to be taken without waiting for the research results. The areas in which Japan can make contribution would be not only sharing technologies to mitigate air pollution emissions but also providing policy implications from the recent success in VOC emission reduction utilizing the voluntary programs.

5. Conclusion

This chapter has reviewed the air pollution policies in Japan since 1960s to date and analyzed them from the perspective of a multi-pollutant multi-effect approach. The analyses showed that the Japanese policies before the 2000s can be generally categorized as in the stage of Single-Pollutant Control Phase 1, and the VOC policy adopted from mid-2000s played an important role in the transition to a multi-pollutant approach. The analysis suggested that VOC policy can be considered as in the transitional period between the Single-Pollutant Control Phase 2 and the Multi-pollutant Control Phase 2.

The experience from the VOC reduction policy indicates the difficulty related to the ex-ante analysis of effectiveness of reduction policies of precursors. Now that Japan is further shifting into a multi-pollutant approach, it is necessary to elucidate the formation mechanisms among the pollutants in its primary scope and their precursors, including photochemical oxidants, $PM_{2.5}$, and VOC, to develop more accurate simulation models which can guide the policy making. To enhance the effectiveness of the atmospheric management, a system to incorporate integrated assessment of various pollutants in addition to the above mentioned substances would be desirable.

Another lesson drawn from the Japan's VOC reduction policy is the potential of voluntary approach in the air pollution reduction. While this specific policy adopted a policy mix of both regulatory and voluntary approaches, it suggests not only the need for further examination on what is the best extent to utilise voluntary approach in pollution prevention, but also the potential for other countries to consider the use of voluntary approach in their air pollution control.

For future study, it would be worth investigating why the Multi-pollutant Control Phase 1 has not been observed in Japan. One possible explanation is that as NO_X, the other important precursor of photochemical oxidants, has been already addressed to a large extent by the time photochemical oxidants became policy priority in the 2000s.

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IV. China's Multi-pollutant Control – Co-Control of Air Pollution

1. Introduction

China's air pollution policies from the beginning of the period of rapid industrialization firmly focused on a single pollutant approach covering a few main primary pollutants, particularly NOX and SO2. However, in recent years, air pollution has become increasingly complex, one of the reasons being the explosive growth in the number of automobiles. As a result, the problem of secondary pollutants such as VOCs, PM2.5, and Ozone have rapidly become much more urgent, hence the need for a more complex multi-pollutant approach.[17]

China's air pollution policies have moved in the direction of the multi-pollutant approach in recent years. Regarding effects, China's research capability in this area has significantly increased in recent years, although it does not yet have a significant influence on the policymaking process. Instead, air pollution reduction targets are mainly set on the basis of cost and technical feasibility. However, China's policymakers appear to be highly interested in MPME style approaches due to their significant potential to reduce costs and increase effectiveness. A major new development in terms of administrative structure is the creation of a regional management system to address domestic transboundary air pollution between provinces. Although this regional management system has had a slow start, in the long run it has the potential to become a domestic LRTAP implementing an MPME approach. These points are explained in more detail below.

2. Concepts

The term MPME is not commonly used in China. Instead, a similar concept, co-control is used. Co-control (协同控制 xie tong kong zhi) refers to multi-pollutant multi-effect control in Chinese. The literal meaning is "coordinated control" or "synergetic control."

[17] A detailed summary of China's air pollution problems, a list of current policies, and recommendations for strengthening them can be found in CCICED 2012.

The meaning is interpreted differently by policy researchers on one hand and policy makers in the Ministry of Environmental Protection (MEP) on the other hand.

"Co-control" is an official government concept, which is included in the *"12th Five-Year Plan" for Air Pollution Control in Key Regions*, where it is defined rather simply as the comprehensive control of several air pollutants (MEP; NDRC; MOF, 2012). Considering the co-control measures included in this Plan, and based on some interviews with related policy practitioners, multi-pollutant control in China means simultaneous control of several air pollutants, and not necessarily based on an analysis of their effects.

A comprehensive definition for "Co-control" has been formulated by researchers from Policy Research Center for Environment and Economy (PRCEE) of MEP. In short, "Co-control" refers to control measures which address the interrelationships or synergies between pollutants (Hu, Tian, & Mao, 2012). In particular, they believe that co-control should focus on synergies between energy and air pollution to achieve more cost effective reductions. The control measure here include not only engineering measures, but also institutional measures. This can be considered to be a multi-effect as well as a multi-pollutant approach, since co-control aims at addressing both the effects of traditional air pollution as well as climate change. Specifically, targeted air pollutants include SO_2, NOx, PM, O_3, CO, POPs, and VOCs, and six types of GHGs: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6. These researchers also target other pollutants like Hg, black carbon, emissions from different types of technical industries.

3. Strengthening the Research Base

China is developing significant research capability to analyse both multiple pollutants and multiple effects. Related air pollution research has been sponsored and funded by several ministries, not only the Ministry of Environmental Protection, but also the Ministry of Science and Technology and the National Development and Reform Commission. In addition, some research is funded by local governments, particularly Beijing.

A special 12th Five Year Plan establishing the Blue Sky Science and Technology Project, was issued on October 24th 2012 by MEP and the Ministry of Science and Technology (MOST), for supporting China's atmospheric pollution control technologies. One of the main objectives in this project is to establish comprehensive technology system for atmospheric pollution control suitable for national condition of complex regional air pollution problems. The Plan designates priority research areas such as human resource development and innovation capability building. Decision making support technology and integration technology for ambient air quality improvement, key pollutant source control technology, atmospheric environment monitoring & early-warning technology are also emphasized. Based on these foundations, research on prevention and control of complex atmospheric pollutants will be carried out (MOST; MEP, 2012).

The Blue Sky Project also established a new national key laboratory for source and control of complex atmospheric pollution at Tsinghai University on February 16th 2013. The laboratory's research will focus on source characteristics and control of complex atmospheric pollution. The laboratory's tasks include research on theory and methodologies tracing complex atmospheric pollution sources, atmospheric pollution control, and establishing a platform of supporting technologies for air quality management. It also aims to provide supporting technologies and measures for regional air pollution control (MEP, 2013).

One study which can be considered to use a broad scope MPME approach is He (2007). This study concluded that by actively implementing policies for clean energy, industrial structure adjustment, improve energy efficiency, green transportation, Beijing in 2010 can reduce 185 thousand ton SO_2 emissions, 415 thousand ton NOx, 56 thousand ton PM_{10}, in the same time reduce, 841 cases of death, 25.9 million ton energy demand of coal, as well as 10.5 million CO_2.

Regarding research on interactions between pollutants, a report by CCICED (2012) shows that research on PM2.5 is becoming more advanced in the analyses of chemical composition from different geographic areas. The report further provides an estimate of the required reduction of precursors to reduce PM2.5.

In sum, China is clearly developing the scientific capability to conduct the analysis necessary for the MPME approach, including analysis of multiple effects. The policy documents do not use the term MPME, but these measures are clearly aimed at its main elements, including analysis of interactions among multiple pollutants as well as multiple effects. Moreover, the official policy documents clearly state that the results of this research are expected to be applied to the development of reduction measures, which will eventually be incorporated into future policies.

4. Transition to a Multi-pollutant Approach

In the past, China's air pollution policy focused on a few primary pollutants such as SO2 and NO2. In the new 12th Five Year Plan for Air Pollution on Key Regions, the scope of pollutants has been expanded to cover the secondary pollutants of Ozone and PM2.5. VOCs are also included.

Therefore, since China is now managing secondary pollutants such as Ozone through the control of multiple primary pollutants (including NOX and VOCs in the case of ozone), it is possible to say that China has reached the early phases of a multi-pollutant approach. China's policymakers were certainly aware of the fact that there are multiple precursors of secondary pollutants, and Chinese scientists have conducted detailed studies on the interactions between the air pollutants. However, it is not clear to what extent the detailed scientific analysis actually influenced the policy; it is more likely that Chinese policymakers were influenced by the knowledge of the general relationship rather than the details of the scientific analysis.

Multi-pollutant control strategies have also been used at the regional level on an ad hoc basis, in the case of the Beijing Olympics, Shanghai World Expo, and the Guangzhou Asian Games. The controlled pollutants – S02, NOX, PM, and VOCs – included secondary pollutants. Advanced monitoring and modeling systems were used to forecast pollution events and directly informed the control measures. Moreover, since these pollution cases were transboundary in nature, domestic regional management frameworks were established, and these were supported by regional modeling. (See CCICED 2012; Zhou and Elder 2013.)

5. Multi-effect Approach

China is not yet at the stage where analysis of effects is formally incorporated into the policymaking process. Instead, targets appear to be mainly determined by technological and economic considerations.

Nevertheless, as mentioned above, considerable effort has been made to develop research capability to analyse multiple effects, as well as interactions among multiple pollutants. It is expected that this capability will play a stronger role in policymaking in the future.

6. Institutional Framework and Capacity: Development of a Regional Management System

China has begun the process to create a regional management system to address domestic transboundary air pollution between provinces. Originally it was based on the Guideline on Strengthening Joint Prevention and Control of Atmospheric Pollution to Improve Air Quality, which was endorsed by the State Council in May 2010. This system was based in part on China's experience with managing air pollution for the Beijing Olympics, Shanghai Expo, and Guangzhou Asian Games (Zhou and Elder 2013). Subsequently, the 12th Five Year Plan on the Prevention and Control of Air Pollution in Key Regions, based on this Guideline, was released on October 29, 2012.

The Key Regions Plan covers three main regions (Beijing-Tianjin-Hebei, Yangtze River Delta, and the Pearl River Delta) and 10 city clusters. It contains a variety of targets and measures. One of its key features is that it includes targets for secondary pollutants of PM2.5 and VOCs, which are not included in the more-broad based National Total Emissions Program. The Plan sets up a framework for discussions between provinces, but it does not include any procedures for requiring any specific agreements or actions. According to interviews with some participants in 2012 and early 2013, progress of this system was rather slow, especially in the Beijing-Tianjin-Hebei region (Lin and Elder, forthcoming). Others have strongly recommended that this system should be significantly strengthened (CCICED 2012).

Despite its current limitations, the Key Regions Plan establishes an institutional framework which could serve as the foundation to implement a flexible domestic MPME approach similar to the LRTAP's Gothenburg Protocol. The necessary modeling and monitoring capabilities may already be available in the three main regions, so the discussion frameworks would be able to establish joint regional plans and policies if they were given sufficient legal authority. Therefore, further strengthening of the legal status of this system is desirable. In some city clusters, further capacity development in terms of modeling and monitoring capability may be necessary.

7. Capacity

Implementation of the MPME approach requires a certain level of scientific and institutional capacity, including for the related human resources. China has made important progress in developing these capacities, especially in the three main regions of the Key Regions Plan. China has developed considerable air pollution research capability, and monitoring has been significantly expanded since 2012. The three main regions also have direct experience in temporary large scale pollution reduction using integrated modeling techniques. Outside of these three main regions, capacity may be much more limited. The regional management framework of the Key Regions Plan has the potential to serve as the institutional framework for implementation of an MPME system. Yet, further institutional strengthening would be required to realize this potential.

8. Conclusion

In terms of the multi-pollutant approach, China can be said to be in the process of moving from single pollutant stage 1 to single pollutant stage 2. It is in the transition process to multi-pollutant stage 1, and it is now in the process of developing research capability for multi-pollutant stage 2. The regional management system has established a framework that could support an integrated MPME approach similar to a domestic LRTAP, but its institutionalization is still in the embryonic stages, and would need considerable time to develop. Although China is making steady progress in capacity development, particularly in the more advanced regions around Beijing, Shanghai, and Guangzhou, more nationwide capacity is needed, and the institutional framework to support implementation of MPME needs to be considerably strengthened. International cooperation would be helpful, especially in terms of additional capacity development and information sharing.

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V. Air Pollution Policies Related to the Multi-Pollutant Multi-Effect Approach under Green Growth in South Korea

1. Multi-Pollutant Relevant Policy Efforts under Green Growth

South Korea (hereinafter called Korea) has actively addressed environmental pollution problems using the Environmental Conservation Act of 1977 and the Clean Air Conservation Act of 1990, which currently defines 61 air pollutants with standards for 7 pollutants including PM and O3.

The concept of the "multi-pollutant and multi-effect (MPME) approach" has not commonly been used and the relevant concept has not formally been discussed in Korea. On the other hand, this review of air pollution policies, policy-relevant plans and discussions in Korea shows that some multi-pollutant relevant policy efforts have been made or have been under way in recent years under the Green Growth policy framework. Major relevant efforts include:

1) Addressing secondary pollutants has been prioritized in the Special Act on Seoul metropolitan Air Quality Improvement (December 2002, Ministry of Environment) and the Air Quality Control Basic Plan in the Capital Region (November 2005, Ministry of Environment).

2) Korean policies are moving in the direction of "risk-based" air pollution management. To prepare for this, the reform of air pollutants management system is being implemented. As a first step, the classification of hazardous air pollutants which are required to be monitored is currently being reformed because the current definitions of classification are not clear and the classification is not consistent[18] (see details below).

[18] Documents from an explanatory meeting regarding "Air Environmental Protection Act Reform" in February, 2013 hosted by the Ministry of Environment, Republic of Korea.

Specifically regarding secondary pollutants, the Special Act on Seoul metropolitan Air Quality Improvement and Air Quality Control Basic Plan in Capital Region policies focus on PM10, NOx, VOCs, and SOx, and prescribe special measures to improve air quality based on identification of the contribution ratio of those pollutants or calculations of acceptable amounts for targeted reductions. For example, in the Special Act on Seoul metropolitan Air Quality Improvement, in order to achieve the revised targets for PM 10 and NO2, it is estimated that targeted reductions are necessary as follows: reductions of NOx by 50%, PM 10 by 65%, SOx by 70%, and VOC by 35%, respectively.

Furthermore, according to a draft of the PM 2015 Management Plan which will introduce standards for PM 2.5, the Korean Government will to control PM 2.5 by using NOx and VOC controls. The main directions of this plan are as follows:

- The focus of PM is shifting from PM 10 to PM 2.5, and management of PM 2.5 pollution sources will be strengthened.
- Various measures for mitigating PM 2.5 will be introduced, such as strengthening emission standards, promoting Low NOx Burners, and strengthening facility management including the introduction of VOC facility management standards.
- However, specific management measures to meet PM 2.5 standards have not been specified when this article was written.

Korea’s air pollution policy is moving in the direction of “risk-based” air pollution management. According to recent major policy discussions, risk-based management is expected to focus on[19]:

- strengthening human health risk-based or emerging human-risk based approaches for air pollution management;
- promoting integrated air pollution management which takes into account air environment, energy management, climate change and public risks;
- formulating comprehensive air management policies taking into account the state of the economy and the possibility of creation of employment.

[19] Summary from “ Discussion Meeting on Advancement for Air Environment Management” which was held in Seoul in February 6th in 2013, hosted by the Ministry of Environment, Republic of Korea, Air Pollution Management Section.

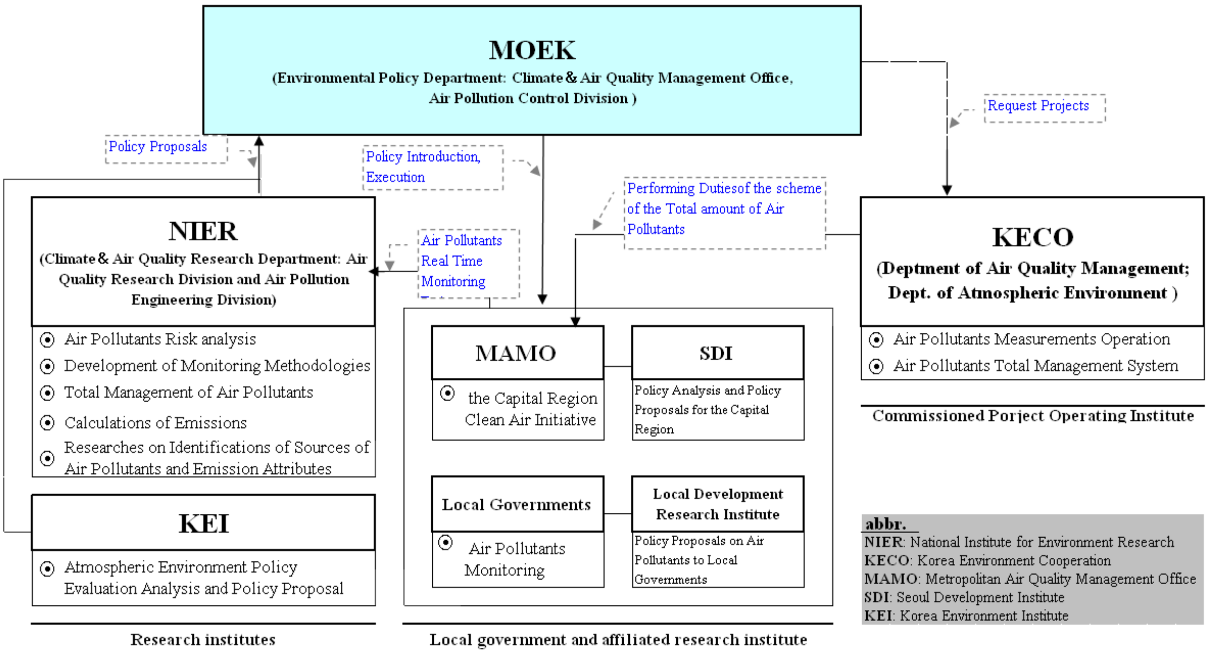
Furthermore, according to "Risk-based Air Environmental Policy Promotion Directions,"[20] the related strategies should focus on:

- toxicology and risk–based air pollution pollutant management;
- scientific improvement in classification system of pollutants;
- establishment and promotion of PM 2.5 pollution management measures.

The above policy efforts and directions indicate that while the current efforts in the context of MPME are at the early stages from the perspective of "multi-pollutant" approach and it is too early to evaluate their policies, it is important to note that relevant efforts are directing toward building blocks of MPME through reforming the management system for risk-based air pollution management which will set up a regulatory system that includes consideration of multiple air pollutants and multiple effects.

2. Relevant Institutions and Administrative Mechanisms

Overall, Korea has a variety of institutions which are structured to engage in comprehensive air pollution management from policy analysis/evaluation and policy proposals through policy making and execution. The major institutions and their linkages are illustrated in the diagram below.



[20] Documents from an explanatory meeting regarding "Clean Air Environmental Conservation Act Reform" in February, 2013 hosted by the Ministry of Environment, Republic of Korea.

Figure 5.1 Air Policy Related Institutions and Their Linkages in Korea

More specifically for mechanisms for MPME approach, the aforementioned classification reform and risk-based approach can be considered to have a potential in developing an effective air pollution management system taking into account multi air pollutants and effects in Korea. Table 5.1 summarizes a draft proposal to reform the current classification system; the draft proposal includes details of reform plan and compared it to the current status.

Table 5.1 Classification System Reform: Current System vs. Reform Draft[21]

Categories	Current Status	Reform Draft
Categorization Standards	None	● Introduction of review and evaluation using risk-based evaluation model to be developed; evaluation indices will be specified in four-fields :toxicity, impacts on ecological systems, total emission amount in air, and degree of air pollution
Procedures for Designation	None	● Establishment of Review/Evaluation Committee for air pollutant (tentative name) to be composed of related experts (NIER). After review and evaluation by the committee, air pollutants will be designated by the order of MOEK
Pollutant Categorizations	Air Pollutants (61 types) - specified hazardous air pollutants (34 types) -VOC air pollutant (14 types) -emission allowable air pollutant (24 types)	● Air Pollutants (85 types) are classified in detail as ; - Group A: hazardous air pollutants to be monitored constantly (55 types) - Group B: specific hazardous air pollutants (37 types) - Group C: air pollutants (8 types)
Management Mechanism	Management mainly focusing on per single air pollutant source	● Risk-based comprehensive and systematic management - including implementation of the management basic plan for the air pollutant group A and B (every 10 years)

[21] Documents from an explanatory meeting regarding “Air Environmental Protection Act Reform” in February, 2013 hosted by the Ministry of Environment, Republic of Korea.

The table indicates that the reform plan has many relevant links with an effective risk-based management mechanism, including developing risk-based evaluation model considering broad scopes of pollutants and risks such as toxicity and impacts on ecosystem management.

By 2013, the Korean Government will have organized the Review/Evaluation Committee for Air Pollutants (tentative name), and established standards including attributes and factors to be considered in classifying air pollutants, and setup the review cycles for those hazardous air pollutants needed to be monitored constantly. Integrated management system will be addressed in the basic plan for the air pollutant group A and B, suggesting that Korea is making a transition to the MPME approach. Details in the plan are not specified yet.

3. Recent Developments and Challenges

As noted above, Korean is steadily building a foundation for risk-based air pollution management considering multiple air pollutants and effects through reforming the air pollution management system. On the other hand, this paper identifies several challenges:

- The concept of risk-based air pollution management itself has been introduced since 1980’s and extensive relevant risk assessment research has been conducted. However, while some of results drawn from this research are reflected in policies, they were not generally accepted by policymakers. It should be noted that the focus of previous risk assessment studies was limited to individual pollutants, and most related research was limited to drafting basic risk assessment frameworks and making supporting documents. Therefore, in order to incorporate recent research on risk-based approaches into actual policies, an integrative MPME perspective is required.

- It is necessary to link MPME approach to effective reductions of secondary pollutants such as PM2.5 and O3. Specifically, more researches are required, such as identification of contribution ratio of O3, identification of contribution ratio of VOC to O3 and PM2.5 respectively, and control of PM10 as secondary pollutant.[22]

[22] Choi Yu-jin, 2013, Presentation source 'Analysis and estimation of the contribution of major sources of VOC' (In Korean), February 26, 2013, Seoul Development Institute.

Furthermore, for PM 2.5 standards starting from 2015, specific measures are required based on MPME approach.

- In addressing both Green Growth and better air quality, integrated control of greenhouse effect gas and air pollutants are required in Korea. For this, the NIER has started collaborative research on integrated climate and air control with International Institute for Applied Systems Analysis (IISA) in 2013. This research will develop a GAINS-Korea model (GHG and Air pollution Interaction and Synergies Model) to be used for this purpose. The GAINS model is an integrated policy evaluation model for simultaneous reductions of greenhouse gasses and air pollutants through analysis of synergies of those. Based on these kinds of efforts, specific measures for integrated control will need to be developed and implemented.

The Korean air pollution research community is currently conducting a variety of risk-based studies considering multiple effects such as economic, health and environmental costs and effects on Air pollution in Korea, which are designed to provide policy-makers appropriate information for evaluating and planning air pollution policies. One example is a study which measures the environmental costs of air pollution impacts in Seoul, which provides policy relevant inputs by quantifying the environmental costs of four air pollution impacts (mortality, morbidity, soiling damage, and poor visibility), using a specific case study of Seoul. This study evaluates several policy options by considering the trade-offs between their costs and benefits.[23] While it is unclear whether the results of this research will be incorporated into policy-making, nevertheless, this research will build a good foundation for further advancing risk-based approaches in Korea in the future.

On the other hand, there are daunting challenges in materializing the current policy plan draft including structuring the above “risk-based comprehensive and systematic management” mechanism, which could be an area for co-producing knowledge internationally.

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[23] Seung-Hoon Yoo, Seung-Jun Kwak and Joo-Suk Lee, “Using a choice experiment to measure the environmental costs of air pollution impacts in Seoul,” Journal of Environmental Management 86, 2008, pp.308-18.

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VI. Conclusion

MPME has been identified as an effective system to address the increasing complexity of air pollution issues and achieve higher levels of pollution reduction in a more cost effective way. The examples of LRTAP and the US have shown that MPME is also useful to address these issues in a wide geographical context with varying local conditions.

The need for MPME has been rapidly increasing in Asia. First, East Asian countries, after making progresses in addressing primary pollutants, commonly face the remaining or worsening pollutions due to secondary pollutants. Second, in China, concentrations of $PM_{2.5}$, one of the secondary pollutants, have become to be recognized as one of the national priority issues. Accordingly, concerns over $PM_{2.5}$ have been increasing in the neighboring countries and there have been moves toward further international cooperation.

The question arises as to whether the MPME approach can be usefully applied in East Asia. The MPME approach under LRTAP is very sophisticated, and requires a fairly high level of scientific capability and perceived common interests. It is also linked to a legally binding international treaty. Many East Asian countries do not have a high level of scientific capability in air pollution, and countries in the region have generally shown reluctance to adopt legally binding agreements. However, the analysis in this paper demonstrated that the MPME approach has a number of elements which do not need to be all developed simultaneously, including an emphasis on secondary pollutants, consideration of interactions between secondary pollutants, consideration of effects, use of a risk-based approach, and the direct or indirect use of scientific analysis in setting the policy.

The case studies shows that some elements of the multi-pollutant approach are already being implemented to varying extents, particularly the multi-pollutant aspect, and their air pollution policies are already evolving in the overall direction of MPME. Japan, after considerable success with single-pollutant approach, shifted in recent years to multi-pollutant approach and moving further through the change in the institutional setup of the scientific advisory board. China has had various policies regulating various different pollutants, but these measures fell short of an integrated multi-pollutant strategy, indicating co-existence of various single-pollutant policies. However, the "co-control" concept mentioned in the Twelfth Five Year Plan has the potential to lead to more advanced stages. Korea has addressed secondary pollutants from 1990's especially around the Seoul metropolitan. For example, a special measure for this area, the Capital Region Clean Air Initiative (2002) was carried out, which included reduction targets and strategies for precursors of PM10 and NO2. Also, all of the case study countries face common challenges in further implementing the MPME approach, including the further development of scientific, administrative, and implementation capacity, although each of these challenges are experienced somewhat differently in each country.

Therefore, this paper concludes that it is clearly feasible to promote the MPME approach in East Asia, particularly if it is done in a partial and stepwise manner. Moreover this paper also concludes that further progress of the MPME approach for air pollution should be promoted through expanded international cooperation. International cooperation could focus on developing common or complementary approaches, capacity building, and knowledge sharing. Now that the TEMM countries have agreed to further cooperate on air pollution, joint promotion of the MPME approach could be a focus, beginning by establishing a common understanding of the different components and stages of MPME, and the current status and goals of each country.

Cooperation does not need to be linked to a legally binding international agreement, as is the case of LRTAP, although that could come later if the countries agree. Instead, cooperation could focus on encouraging the further development of domestic policies, which China, Korea, and Japan have already unilaterally decided to do anyway. Even in the case of the US, the MPME approach does not easily fit with the legal framework, but the USEPA has had some success in promoting voluntary implementation of several aspects since it is more cost effective than traditional approaches. Also, in this regard, the successful reduction of VOCs through a policy mix of both regulatory and voluntary approaches in Japan indicates potentials for the use of voluntary approaches.

It should be noted that this paper did not analyze the situation of other East Asian countries which have considerably less scientific and institutional capacity compared to Japan, Korea, and even China. Nevertheless, the analysis in this paper shows that these countries may also be able to take initial steps following the example of others, if MPME is conceived as a series elements which can be adopted in stages. International cooperation may be very helpful here, especially regarding capacity development and information sharing.

Current international cooperation frameworks may be able to help to promote the MPME approach, but in order to do so they would need to expand the scope of their activities and upgrade their own capabilities and resources. The East Asian Acid Deposition and Monitoring Network (EANET) provides a foundation for monitoring, but its current scope only includes primary pollutants, and not secondary pollutants. It also does not formally include modeling. Long Range Transport (LTP), a joint research project among Korea, China, and Japan, includes PM10 and O3, but the scale of activities is small. The Tripartite Environment Ministers Meeting, which has sponsored research on ozone in the past, recently decided to launch a policy dialogue on air pollution, so there appears to be momentum for strengthening international cooperation.

In order to strengthen international cooperation to promote the MPME approach, the institutional framework of international cooperation in East Asia would need to be strengthened. It would not necessarily need a very large commitment of resources, but it would need to be greater than the present levels. It is beyond the scope of this paper to discuss how to do this.

Overall, the implication drawn from this paper for the discussions on the further international cooperation are as follows. First, it is feasible for countries in the region to begin developing the MPME approach in a stepwise manner. Second, the practical feasibility of developing the MPME approach in East Asia by showing that the MPME approach has a variety of elements, and that the elements can be developed in the stepwise approach, without being linked to a legally binding treaty, this paper it. Third, international cooperation can utilize the elements of the MPME approach implemented by participating countries unilaterally in their domestic air pollution policy frameworks. Fourth, even countries with little capacity can still start working towards the MPME approach starting with basic elements, and borrowing results from elsewhere. So there is no good reason for countries in the region to not take steps which can increase the cost effectiveness of air pollution reduction.

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