GLOBAL ATMOSPHERIC POLLUTION FORUM

Integrated assessment tools The Greenhouse and Air pollution Interactions and Synergies (GAINS) model

Les outils pour l'évaluation intégrée des bénéfices Le modèle GAINS

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1. Introduction

Many of the traditional air pollutants and greenhouse gases have common sources. These emissions interact in the atmosphere and, separately or jointly, cause a variety of environmental effects at the local, regional and global scales. A wealth of literature has pointed out that capturing synergies and avoiding trade-offs when addressing the two problems simultaneously through a single set of technologies or policy measures offers potentially large cost reductions and additional benefits.

However, there are important differences at the temporal and spatial scales between air pollution control and climate change effects. Benefits from reduced air pollution are more certain, they occur earlier, and closer to the places where measures are taken, while climate impact is long-term and global. These mismatches of scales are mirrored by a separation of the current scientific and policy frameworks that address these problems [Swart *et al.,* 2004].

Numerous studies have identified a variety of co-benefits of greenhouse gas mitigation on air pollution for industrialized and developing countries. In many cases, when measured using standard economic techniques, the health and environmental benefits add up to substantial fractions of the direct mitigation costs. Carbonization strategies also generate significant direct cost savings because of reduced air pollution control costs. All this highlights the urgency for the establishment of an integrated approach for greenhouse gas mitigation and air pollution control strategies [Barker *et al.,* 2007].

2. Integrated assessment of co-benefits

Various integrated assessment techniques have been developed to address various aspects that could reveal potential synergies and trade-offs between greenhouse gas mitigation and climate change. Some assessments are entirely bottom-up and static, and focus on a single sector. Others include multi sector or economy-wide general equilibrium effects. Methodological differences are a major source of uncertainties when estimating co-benefits, and it is still a challenge to derive a complete picture of total co-benefits [Barker *et al.,* 2007].

Despite methodological differences, a consistent picture emerges from the studies conducted in industrialized countries in North America and Europe, as well as for developing countries in Latin America and Asia. As summarized in the Fourth Assessment Report of IPCC [Barker *et al.,* 2007], assessments focusing exclusively on emissions see moderate CO_2 mitigation strategies (10-20% CO_2 reduction in the next 20 years compared to the baseline projection) leading to 10-20 percent lower SO_2 emissions and 5 to 10 percent lower NO_x and PM emissions. Other studies, which explore resulting health impacts, demonstrate substantial benefits on human health. These depend, inter alia, on the level at which air pollution emissions are controlled and how strongly the source sector contributes to population exposure. Studies calculate for Asian and Latin American countries several tens of thousands of premature deaths that could be avoided annually as a side-effect of moderate CO_2 mitigation strategies. Studies for

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Europe, North America and Korea reveal fewer, but nevertheless substantial health benefits from moderate CO_2 mitigation strategies.

Several authors went a step further and conducted an economic valuation of these health effects in order to arrive at a monetary quantification of the benefits, which can then directly be compared with mitigation costs. While the monetization of health benefits remains controversial, calculated benefits range from 2 US-$/t CO_2 up to a hundred or more US-$/t CO_2. This wide range is partially explained by differences in methodological approaches, e.g., whether assessments include the full range of pollutants (including PM), as well as on the contribution of avoided emissions to population exposure.

Despite the large range of benefit estimates, all studies agree that monetized health benefits make up a substantial fraction of mitigation costs, ranging from 30-50 percent of estimated mitigation costs up to a factor of three to four. Particularly in developing countries, several of the studies indicate that there is scope for measures with health benefits that exceed mitigation costs.

Such potential for no-regret measures in developing countries are consistently confirmed by even more comprehensive integrated assessment studies applying a general-equilibrium modelling approach, which takes into account economic feedback within the economy.

Co-benefits from CO_2 mitigation on air pollution impacts have been found to be largest in developing countries, where air pollutants are often emitted without stringent emission control legislation. Most industrialized countries, however, enforce comprehensive legal frameworks to safeguard local air quality. An increasing number of studies demonstrate significant savings from GHG mitigation strategies on compliance costs for such air quality legislation. Estimates of cost savings range from 10-20 percent in the short term [e.g., Syri *et al.,* 2001] up to full compensation of the costs of a combined strategy in the long-term [van Harmelen *et al.,* 2002]. Cost savings are found sensitive, inter alia, towards the degree flexible mechanisms are applied in a GHG strategy [Van Vuuren *et al.,* 2006].

3. Integrated assessment models

Most of the above findings on co-benefits that are reported in the Fourth Assessment Report of IPCC [Barker *et al.,* 2007] emerge from targeted scientific case studies that have been conducted with different methodologies by different authors for a specific country or world region and subsequently been published in the scientific literature. Recently, several integrated assessment frameworks have been developed that allow systematic analyses of co-benefits for different countries or world regions based on a harmonized methodology. In addition, such integrated models also facilitate a targeted analysis of strategies that maximize co-benefits between air pollution control and greenhouse gas mitigation. Two of these models, i.e., the Greenhouse gas – Air Pollution Interaction and Synergies (GAINS) model developed at the International Institute for Applied Systems Analysis (IIASA), and the Integrated Environmental Strategies (IES) model of the U.S. Environmental Protection Agency, have been applied in a practical context to different countries in different world regions.

3.1. The GAINS model

The Greenhouse gas and Air pollution Interactions and Synergies (GAINS) model explores cost-effective strategies to reduce emissions of greenhouse gases and conventional air pollutants. The GAINS model produces emission scenarios for all major air pollutants for any exogenously supplied projection of future economic activities, it estimates abatement potentials and costs and takes full account of the interactions in abatement between various pollutants [Klaassen *et al.,* 2004]. Essentially, the GAINS model follows pollutants from their driving forces (i.e., economic activities such as energy consumption, agricultural production, industrial activities, etc.), it considers region- and source-specific emission characteristics, it analyzes the potentials for reducing emissions through a variety of technical and non-technical measures and estimates the associated costs, it simulates the fate and dispersion of emissions in the atmosphere and it computes impact indicators for human health, ecosystems, and greenhouse gas emissions.

The GAINS model considers emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$ and PM_{10}), ammonia (NH_3) and volatile organic compounds (VOC) as well of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O) and the three F-gases that are included in the Kyoto protocol. It quantifies health impacts from fine particles and ground-level ozone, excess deposition of acidifying (sulphur and nitrogen) compounds and excess nitrogen input to ecosystems, and total greenhouse gas emissions using the global warming potentials specified in the Kyoto protocol (Figure 1). GAINS constitutes an extension of the RAINS (Regional Air Pollution Information and Simulation) model [Schöpp *et al.,* 1999] to greenhouse gases with special emphasis on the interactions between air pollutants and greenhouse gas emissions.

The GAINS model has been applied in Europe, China and India. These GAINS implementations holds economic statistics, energy and agricultural projections and emission inventories for 42 countries in Europe, for 32 administrative regions (provinces) in China and 23 States in India. Based on source-receptor relationships derived from sample of calculations with the EMEP model for Europe [Simpson *et al.,* 2003] and the TM5 [Krol *et al.,* 2005] atmospheric chemistry and transport model for Asia, GAINS computes air quality indicators for rural areas with a 1 degree*1 degree spatial resolution [Dentener,

	PM	SO_2	NO_x	VOC	NH_3	CO_2	CH_4	N_2O	CFCs HFCs SF_6
Health impacts:									
PM	√	√	√	√	√				
O_3			√	√			√		
Vegetation damage:									
O_3			√	√			√		
Acidification		√	√		√				
Eutrophication			√		√				
Radiative forcing:									
- direct						√	√	√	√
- via aerosols	√	√	√	√	√				
- via OH			√	√			√		

Figure 1.
The GAINS multi-pollutant/multi-effect framework.

2008]. For estimating health impacts, GAINS calculates urban concentrations of $PM_{2.5}$ for the major cities in India and China.

GAINS uses exogenously supplied projections of energy consumption and industrial as well as agricultural activities up to 2030 as economic driver for its emission projections. Based on these activity projections, GAINS considers more than 160 options for mitigating CO_2 emissions, 28 options for methane, 18 options for N_2O and 22 options for F-gases [Klaassen *et al.,* 2005, Höglund-Isaksson and Mechler, 2005, Winiwarter, 2005, Tohka, 2005]. For air pollutants (SO_2, NO_x, PM, NH_3, VOC), GAINS includes in total more than 1 500 emission control measures [Cofala and Syri, 1998a, Cofala and Syri, 1998b, Klimont *et al.,* 2000, Klimont *et al.,* 2002]. The model quantifies for each of the emission source regions the mitigation potentials for each of these options and the associated costs. The GAINS database contains cost parameters that are derived from the international literature and country expert information. It is in the nature of the subject, however, that much of this cost information originates from practical experience in Western countries, while there are very few observations of emission control costs in developing countries. It is known, however, that in Asian countries local prices for certain domestically produced technologies are lower than on the world market, inter alia, due to lower labour costs. Therefore, the economic analysis in GAINS-Asia adjusts costs for emission control equipment considering the share of labour costs and local purchasing power in comparison to the market exchange rates.

GAINS quantifies health impacts that are attributable to the human exposure to fine particulate matter ($PM_{2.5}$), which is formed from primary emissions of particles and as secondary products of SO_2, NO_x and NH_3. As an indicator for health impacts, the assessment quantifies the loss in statistical life expectancy [Mechler *et al.,* 2002] based on evidence from international epidemiological long-term studies that followed the survival of cohorts over several decades under different PM exposure [e.g., Pope *et al.,* 2002]. Uncertainties about the transferability of the exposure-response functions that have been derived for typical Western conditions to developing countries are addressed by systematic sensitivity calculations.

GAINS can be used for a number of different purposes. As a database it provides activity data and control strategies for future scenarios; as an emission model it estimates emissions and costs of current of future air quality policies; with its reduced-form atmospheric dispersion model GAINS can calculate the reductions in environmental impacts as a consequence of changed air pollution policies. In addition, the optimization module of the GAINS model can be used to find sets of cost-effective control measures that meet given environmental objectives at a future point in time. These environmental objectives ("targets") can be defined either in terms of emissions or in terms of impacts, such as loss of life expectancy due to the exposure to fine particles ($PM_{2.5}$). A detailed description of the optimization module of GAINS is provided in Wagner *et al.,* 2007.

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