

Integrated assessment modelling

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1. Introduction

To provide policy-relevant information on effective control strategies for reducing negative impacts of aerosols on human health and climate change, integrated assessment models are being developed. Such models bring together scientific information on the individual aspects of atmospheric PM (i.e. emissions, atmospheric transport and transformation, health impacts) into a single scheme, so that responses of the overall system to changes of individual elements can be explored. Integrated models allow identifying strategies at the local, regional and global levels that protect the atmosphere while imposing the least burden on economic development. In Austria, integrated models covering aerosols have been created by the International Institute for Applied Systems Analysis (IIASA).

IIASA develops innovative modelling tools that enable search for sets of emission control measures that simultaneously meet environmental targets on air quality and greenhouse gas reductions at least costs. Of particular importance are emissions of aerosol precursors (e.g. SO₂, NO_x, NH₃, VOC, PM_{2.5}), which deteriorate air quality at the local scale and cause negative impacts on human health, agricultural crops, natural vegetation and man-made material. At the same time, these emissions influence near-term climate change, as they exert radiative forcing at the regional scale. The analysis takes full account of the interactions between different control measures and pollutants, and thus allows highlighting synergies and trade-offs of particular strategies.

Strategies designed by IIASA are being used as a foundation for short- to long-term policy development by decision makers in the developed and developing worlds.

2. IIASA's approach

IIASA's interdisciplinary research develops a systems perspective that encompasses a variety of aspects that are relevant for environmentally and economically effective pollution control strategies. Its GAINS (Greenhouse gas – Air pollution Interactions and Synergies) model addresses threats to human health posed by fine particulates and ground-level ozone, risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated levels of ozone, as well as radiative forcing. These impacts are considered in a multi-pollutant context, quantifying the contributions of

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sulfur dioxide (SO₂), nitrogen oxides (NO_x), ammonia (NH₃), non-methane volatile organic compounds (VOC), and primary emissions of fine (PM_{2.5}) and coarse (PM_{2.5}-PM₁₀) particles. GAINS also accounts for emissions of the six greenhouse gases that are included in the Kyoto protocol, i.e., carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and the three F-gases (Table 1).

Table 1: The multi-pollutant/multi-effect approach of the GAINS model (open circles indicate linkages that are not yet considered in GAINS).

	PM	SO ₂	NO _x	VOC	NH ₃	CO ₂	CH ₄	N ₂ O	HFCs PFCs SF ₆
Health impacts									
- ambient particulate matter	•	•	•	•	•				
- ground-level ozone			•	•				□	
Vegetation and ecosystems damage									
- ground-level ozone			•	•				□	
- acidification		•	•		•				
- eutrophication			•		•				
Climate impacts									
- Long-term radiative forcing at the global scale	•	•	•	•	•	•	•	•	•
- Instantaneous radiative forcing at the regional scale	•	•	•	•	•				

GAINS holds the essential information on all aspects listed above for 43 European countries and links this data in such a way that the environmental implications of alternative assumptions on economic development and emission control strategies can be assessed. On-line access to the model and to all input data is available at <http://gains.iiasa.ac.at>. The GAINS model allows simulation of the costs and environmental impacts of user-defined emission control scenarios. Its optimization mode balances emission control measures across countries, pollutants and economic sectors in such a way that user-defined target levels on the various environmental impacts are met at least costs.

To describe these interactions, the GAINS model brings together scientific knowledge and quality-controlled data on future socio-economic driving

forces of emissions, on the technical and economic features of the available emission control options, on the chemical transformation and dispersion of pollutants in the atmosphere, and the resulting impacts on human health and the environment. The GAINS model combines information on:

- economic development that determines current and future levels of anthropogenic activities
- historic statistics and future projections on the levels of emission generating activities (e.g., energy use, industrial production, agricultural activities, etc.)
- emission characteristics of the various activities
- measures that are available to reduce emissions from all sources
- the costs of such measures
- the chemical conversion and transport of emissions in the atmosphere
- the impacts of pollution to human health, vegetation and ecosystems
- the impacts of these pollutants on radiative forcing in the near- and long-term

With such a systems perspective, GAINS enables a holistic assessment of the costs and environmental benefits of alternative emission control strategies. In particular, its optimization approach facilitates the design of portfolios of measures (to be taken in different sectors, for different pollutants and in different regions) that achieve user-defined air quality and climate objectives at least cost.

Such a systems perspective is particularly relevant for acting on both fronts against climate change and local air pollution. As many measures to reduce one type of pollution have (positive or negative) impacts on the other, there exist considerable co-benefits as well as potential trade-offs. For example, measures that aim to reduce fossil fuel combustion in order to reduce greenhouse gas emissions will have ancillary benefits for regional air pollutants; improving structural measures in agriculture can reduce both regional air pollution and climate change; the abatement of CH₄, which is both an ozone precursor and a greenhouse gas, has synergistic effects, and some cheap abatement measures may be highly cost-effective. In contrast, enhanced use of diesel cars would reduce CO₂ emissions, while it would exacerbate health effects from fine particulate matter unless efficient particle filters are applied.

IIASA's analysis provides a comprehensive framework to systematically address such interactions, and to search for strategies that maximize synergies for multiple benefits. Results find interest in international science and are adopted for policy processes.

3. Interactions between air quality and climate change

Analysis with GAINS demonstrates that cost-effective strategies, which selectively allocate specific reduction measures across economic sectors, pollutants and regions, could achieve the air quality improvements of a conventional across-the-board approach at only 50% of the costs. In developing countries, measures to eliminate indoor pollution from the combustion of solid fuels will form an integral element of such an air pollution control strategy. However, well-designed air pollution control strategies can also reduce emissions of greenhouse gases. For achieving given targets on ambient air quality, the cost of air pollution can be further reduced by adopting certain low carbon measures, such as energy efficiency improvements, fuel substitution, co-generation of heat and power, integrated coal gasification combined cycle (IGCC) plants. For instance, a model study for India and China (Rafaj et al. 2009) demonstrates that such measures would reduce air pollution at lower costs than a conventional approach that relies on technical end-of-pipe emission control measures. At the same time greenhouse gas emissions would be lower (see Figure 1).

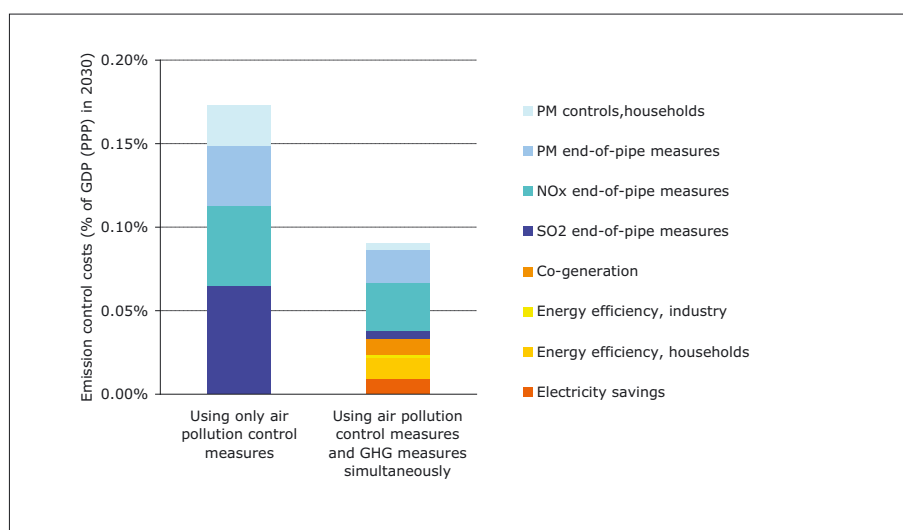


Figure 1: Emission control costs for reducing PM health impacts in China by 50% in 2030.

The GAINS model presents clear evidence that co-control of CO₂ and air pollutants leads to significant co-benefits of greenhouse gas mitigation on non-climate policy objectives, inter alia for the protection of human health, ecosystems and agricultural production. Such co-benefits occur both in industrialized and developing countries, and they emerge in the near term and close to the locations where mitigation measures are taken. Thus, a comprehensive

assessment of the costs and benefits of greenhouse gas mitigation must not ignore such co-benefits (Shindell et al. 2008).

Some of the emission reductions that occur as a co-control of CO₂ mitigation (e.g. of SO₂ emissions) lead to additional warming in the near term, as presence of such short-lived substances exert in the atmosphere exert a cooling effect upon formation of light reflecting particles. Thus, such co-controls of cooling agents will compensate some of the climate benefits from CO₂ mitigation in the next few decades. At the same time, optical active particles (black carbon, BC) which absorb light will contribute to warming and counter the effect of the reflecting particles. The direction and extent of such combined effects is matter of intense scientific debate and will strongly depend on the respective conditions (Penner et al. 2010, Borken-Kleefeld et al. 2010). Thus improving the database on BC emissions is a high priority (Lamarque et al. 2010, Koch et al. 2010, Bond et al. 2004). Also, the uncertainty in the causal chain between anthropogenic activities and climate change deserves to be scrutinized (Prather et al. 2009).

4. Application in science and policy

IIASA's analysis has been applied for key international environmental agreements in Europe to inform negotiators about cost-effective sets of emission reductions that achieve environmental policy targets at least cost. Under the Convention on Long-range Transboundary Air Pollution, the RAINS model, i.e., the predecessor of the GAINS model focusing on air quality only, was used to identify emission ceilings for the negotiations of the Second Sulfur Protocol in 1994 and the Gothenburg multi-pollutant/multi-effect Protocol in 1999, and the revision of the Gothenburg Protocol in 2012. For the European Union, the GAINS model developed the quantitative proposals for the Directive on National Emission Ceilings in 1999, and provided the scientific backbone of the 'Clean Air For Europe' programme that prepared the knowledge base for the EU Thematic Strategy on Air Pollution in 2005. Currently, GAINS is used to inform European negotiators for the revised Emission Ceilings Directive of the EU (Amann et al. 2010, Cofala et al. 2009). In the up-run for the Copenhagen Climate Summit, IIASA developed estimates of mitigation potentials and costs of greenhouse gas emission reductions for the Annex I countries (Amann et al. 2008, Amann et al. 2009).

A decisive element to apply an integrated assessment model in policy is the ability to relate the environmental pressures (emissions) and the abatement scenarios to the respective policy targets. In Figure 2, the loss of statistical life expectancy is the target value displayed against modelled concentrations of anthropogenic PM_{2.5}.

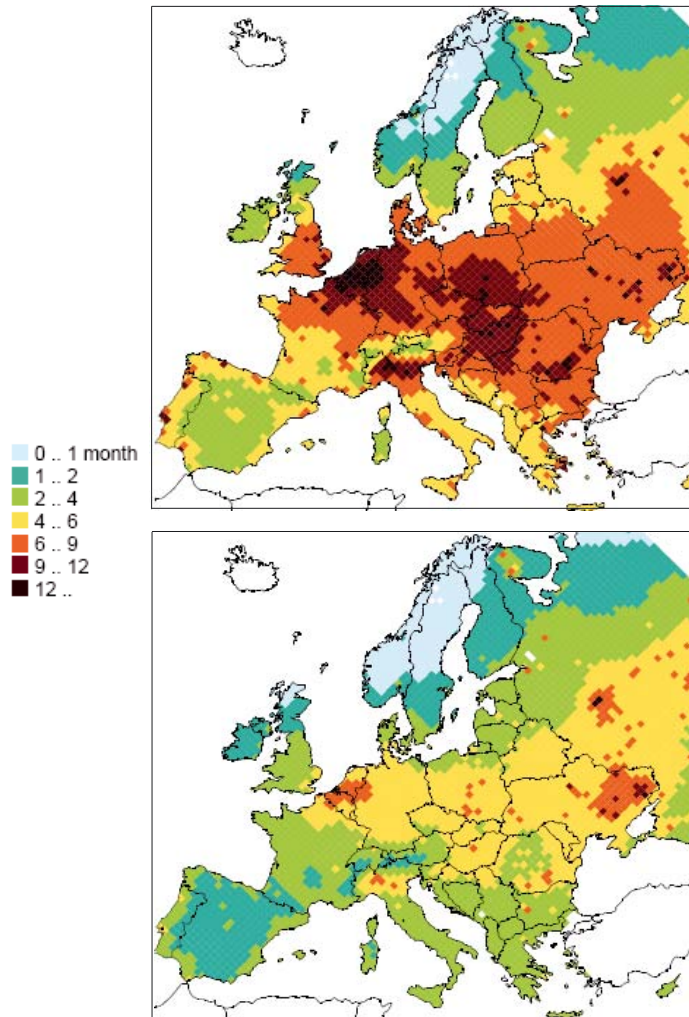


Figure 2: GAINS estimates of loss in statistical life expectancy attributable to exposure to PM_{2.5} from anthropogenic sources (in months). Upper panel: 2000; lower panel: baseline projection for 2020. These estimates have been used in the Clean Air For Europe (CAFE) program of the European Commission to establish the air quality targets of the EU Thematic Strategy on Air Pollution.

Recently, IIASA also contributed to the 'Assessment of Black Carbon and Tropospheric Ozone' of the United Nations Environment Program (UNEP 2011; Shindell et al. 2012) and explored the scope for control of short-lived substances that could complement efforts to reduce long-lived greenhouse gases and thereby minimize the negative climate impacts of SO₂ controls.

Based on the GAINS model, IIASA identified 16 measures that reduce emissions of CH₄ and black carbon so that the global radiative forcing from these substances could be cut by two thirds in the near term. These measures, all of which are already successfully applied in practice in different parts of the world, are complementary to CO₂ mitigation measures. They include measures to control emissions of CH₄ from coal mines, production and distribution of oil and gas, from waste management and livestock farming, as well as measures directed at emissions of black carbon (e.g., particle filters for diesel engines, clean cooking stoves, agricultural waste burning, etc.). The analysis shows that rapid implementation of these measures throughout the world could reduce global temperature increase in the next few decades by up to 0.5 (0.3-0.7) degrees. Larger reductions would occur in Asia, where the main potential for further reductions of these substances exists, and in the Arctic. Most of these measures affect sources that are not in the focus of CO₂ mitigation, and would thus not be taken in the interest of climate change mitigation. However, together with CO₂ mitigation, these measures would substantially increase the chance to keep the global temperature increase below 2 degrees (see Figure 3).

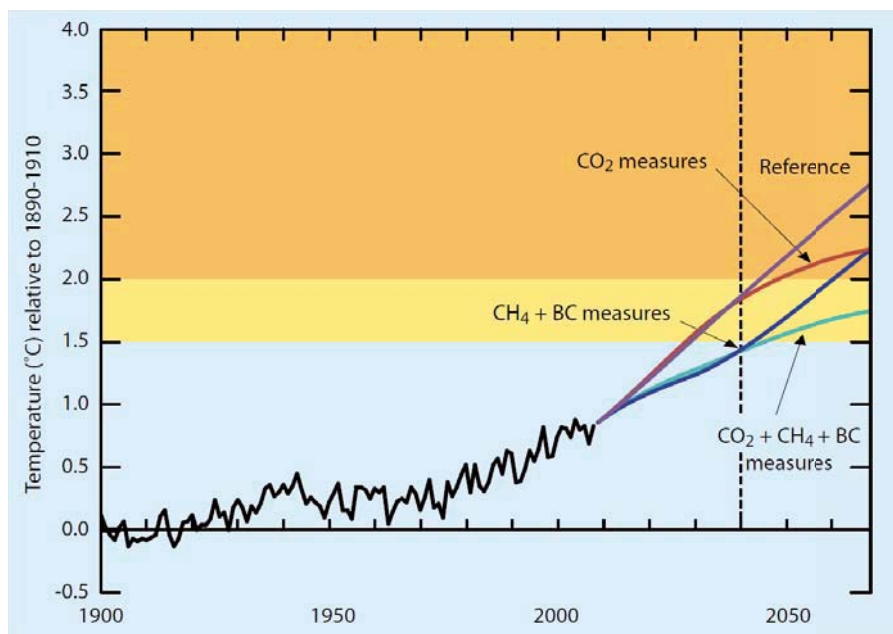


Figure 3. Observed deviation of temperature to 2009 and projections under various scenarios. Immediate implementation of the identified BC and CH₄ measures, together with measures to reduce CO₂ emissions, would greatly improve the chances of keeping Earth's temperature increase to less than 2°C relative to pre-industrial levels. The bulk of the benefits of CH₄ and BC measure are realized by 2040 (dashed vertical line). Source: UNEP (2011), reproduced with permission.

In addition to their climate impacts, these measures have substantial benefits on human health and agricultural production as they also lead to improved air quality at the local scale. Since they affect air pollution emissions and impacts for which (inter-) national policy institutions are already in place, they could be implemented under existing local and regional air quality legislation regimes. Furthermore, many of these measures would contribute to existing development objectives (e.g., access to clean energy and water, waste management, introduction of more efficient energy production technologies, etc.).

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