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Subject: sulfur discussion paper
Date: Wed, 05 Mar 1997 17:18:58 +0000

Sulfur Emissions in New IPCC Scenarios

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SUMMARY OF PROPOSED ACTIVITIES

1. Review and comments of present sulfur discussion paper
2. Revision by sulfur paper lead author
3. Preparation of comparison of regional sulfur scenarios (by lead author with inputs from other members of writing team and experts)

Timing: August 1997.

4. Specification of minimum and desirable sulfur emission scenario characteristics and specification (for modeling teams in open process)
5. Establishment of key relationships between sulfur emissions and other salient scenario driving force variables (income, technological change environmental, non-GHG policies) using the simple metric of sulfur to carbon emission ratios.
6. Adoption of specific sulfur control scenarios in conformity with overall scenario ``storylines''.
7. Distribution of ``template'' sulfur scenarios to selected modeling teams for assessment of climate and acidification impacts of sulfur scenarios.

Timing: End of 1997.

DISCUSSION PAPER

1. Introduction

The purpose of this discussion paper is to review briefly the assumptions on sulfur emissions in the IS92 IPCC scenarios, advances in knowledge and modeling of future sulfur emission scenarios since IS92, as well as to initiate a discussion on how to incorporate future sulfur emissions trends into the new IPCC emissions scenarios. The present draft will be revised based on feedback received within the members of the IPCC writing team as well as additional outside experts.

2. Sulfur emissions in IS92

The treatment of sulfur emissions in the IS92 scenarios was comprehensive. In addition to the dominant energy sector emissions, also sulfur emissions from industrial processes and land-use changes (biomass burning) and (a constant flow) of natural sources were included in the scenarios.

1990 base year values in IS92 were as follows in MtS (Million tons, or Tg, elemental sulfur; to obtain weight as SO2 multiply by 2.):

Energy Sector: 65 MtS
Other Industry: 8 MtS
Biomass burning: 2 MtS
Natural: 22 MtS

TOTAL: 98 MtS

These global base year values are well within the range given by global sulfur emission inventories of 4 to 45 MtS natural sources and 65 to 90 MtS anthropogenic sources in 1990 (IPCC, 1995:135-141). A comparison of 1990 base year sulfur emission values from a number of scenarios and integrated assessment models is enclosed as attachment.

However, as observed in the evaluation of the IS92 scenarios (Alcamo et al., 1995) regional sulfur emissions assumed in IS92 (e.g. for China) are much more uncertain. There is for instance up to a factor two difference between regionalized estimated of global inventories and aggregates of national and regional emissions inventories. Thus, the good agreement of base year values of IS92 at the global level masks important differences and uncertainties at the regional level.

A first important task for the new IPCC scenarios is therefore to update the regional sulfur emissions baseline values with the results of latest regional sulfur emissions inventories. Such inventories are available for Europe through EMEP and CORINAIR, North America (NAPAP), and more recently also for Asia (e.g. the Worldbank sulfur project, Foell et al., 1995).

Improved modeling of regional sulfur emissions (and deposition, i.e. impacts) patterns would also require a redefinition of the world regions as used in the IS92 scenario series. For instance, Canada is included in the region OECD-Europe, and the IS92 region "South Asia" includes both the Indian subcontinent as well as Indonesia. Their important differences in resource endowments lead to different patterns of sulfur emissions. Their differing predominant weather patterns and distinct ecosystems lead to differing acidic deposition patterns and impacts. Both factors preclude their aggregation into one single regional model. Active inputs from representatives of all respective modeling communities (regional acidification impacts, regional climate modelers, energy systems analysts) will be sought on this issue and lessons learned within EMF activities (M. Schlesinger) on appropriate sulfur regionalization (6 world regions) will be extremely valuable.

Concerning future emissions of sulfur the IS92 scenarios project global anthropogenic emissions of between 150 to 200 MtS by 2050 and between 140 to 230 MtS by 2100 in the high growth cases, and of around 80-90 and 60 MtS in the two low scenarios (IS92c and IS92d) by 2050 and 2100 respectively. The IS92 scenario evaluation (Alcamo et al., 1995:281-282) concluded that the IS92 scenario series only partially reflect recent legislation to reduce sulfur emissions (e.g. the amendments to the Clean Air Act in the US or the Second European sulfur protocol). Hence, particularly regional sulfur emissions in OECD countries projected in IS92 are much higher than more recent scenarios taking account these legislative changes (as also discussed by IPCC, 1995:155-156). For instance the recent scenarios of the Commission of the European Communities (EC, 1996) indicate that sulfur emissions by 2020 will be between 64 to 77 percent below 1990 emissions levels, or between less than 2 to 3 MtS, compared to 8 in 1990. For comparison, the IS92 scenarios project for OECD Europe (including Canada) sulfur emissions between 8.4 (IS92a and IS92b) and 11.7 (all other scenarios) MtS by 2020, i.e. between 2 to 30 percent lower than in 1990 (12 MtS).

In addition, integrated assessment models are increasingly able to model in greater detail driving forces of sulfur emissions as well as acidification impacts (cf. discussion below). These model simulations suggest that particularly in Asia acidification impacts would require substantial sulfur emission control measures already much earlier than 2050. The resulting global sulfur emissions are substantially lower than suggested in the IS92 series: typically in the range between 20 to 80 MtS by 2050 and between 20 to 120 MtS by 2100. (A comparison of global sulfur emissions scenarios with and without specific sulfur control assumptions in enclosed as attachment.)

3. What's New since IS92 (scientific front)

The importance of aerosols including those from sulfur emissions is by now widely recognized and considerable progress has been made to quantify their effect on regional climate, both in large GCM simulations as well as in more simplified integrated assessment models, e.g. MAGICC's SCENGEN module (needs checking for details with Mike Hulme) or Michael Schlesinger's work within the EMF (current status: uncertain). The importance of sulfur emissions as input to climate models is therefore larger than ever.

As a result of a major World Bank study on acid rain in Asia also improved national and regional sulfur emissions inventories have become available (Foell et al., 1995). Improved emissions inventories outside North America, Europe (including the European part of the former USSR), and Asia (excluding Oceania, for which only sparse data seems to be available) have not been made available since publication of IS92.
As a result, models and scenarios continue to rely on estimates, largely based on approximate mass and sulfur balance approaches in the world regions for the Middle East, Southern Africa, and Latin America (cf. discussion of data availability below).

Similarly, acidification impact models are increasingly being refined for regions outside OECD in particular for Asia. Acidification impact studies for unabated sulfur emissions of coal intensive ``business as usual'' scenarios indicate exceedance of critical loads of up to a factor 10 already within the next three to four decades (Amann et al., 1995) with enormous impacts on natural ecosystems as well as important foodcrops (Fischer et al., 1996).

Increasingly also energy sector and integrated assessment models link regional acidification models with simplified climate models enabling joint analysis of sulfur and climate policies and impacts. Examples include the IMAGE model (Posch et al., 1996) and the IIASA integrated assessment model (Rogner and Nakicenovic, 1996) that are linked with the acidification model RAINS for Europe and Asia, the AIM (Morita et al., 1994) model for Asia, or ???? for North America. These models extend earlier energy sector models that dealt with a comparative costs assessment of isolated sulfur and carbon reductions, and joint mitigation respectively, such as the OECD GREEN model (Complainville and Martins, 1994). The state of knowledge of joint benefits of sulfur and carbon emission reductions was reviewed in the 1995 IPCC WG III report (IPCC, 1996: 215-218) and is expanding rapidly.

4. Data requirements

The most obvious data requirements concern of course comprehensiveness of sulfur emissions by major source category (anthropogenic and natural, energy sector and other industrial sources). Here the data model of the IS92 scenarios appears appropriate and would only require a reassessment in view of most recent data concerning regional emissions (particularly in China, where data uncertainties seem largest).

A more difficult question concerns spatial disaggregation. Independent from the question of which formal models are being used to check for scenario consistency, the outmost spatial detail currently in driving force models with global coverage available is at the level of world regions (typically around 10, but going up to around 20 world regions). Both climate as well as acidification models require inputs at finer spatial resolution. It is unclear at present what would constitute a ``minimum'' or ``desirable'' level of spatial disaggregation for the variety of user communities of new IPCC scenarios. Existing model links (like with the RAINS model) could be used in some regions like Europe and Asia to generate spatially highly disaggregated sulfur emission and deposition maps as inputs for climate models and for impact assessment studies (e.g. for agricultural crop yield models). In their most advanced versions the model links even incorporate regionalized differential growth trends and thus improve on the standard practice of renormalizing base year spatial emission and deposition patterns linearly with a particular sulfur emissions scenario.

For regions where similar links are unavailable, more simplified procedures will need to be devised, keeping in mind the overall tight time frame of the scenario exercise. Two data sets (are there more??) appear available for regionalized sulfur emission patterns: the Oak Ridge GAIA data set (spatial resolution: ????) and the Spiro et al. (1992) data set (spatial resolution: one degree by one degree).

An open (but extremely critical) issue remaining to be resolved is to identify mechanisms and responsible groups that could provide the link between the spatial resolution of the new IPCC scenarios sulfur emissions to whatever final geographical scales required by impact assessment and climate models.

5. Scenarios and Sulfur Policies

There are two major sets of driving force variable that influence future sulfur emissions. 1. Level and structure of energy supply and end use, and 2. degree of sulfur control policies assumed. (Because of the dominance of energy related sulfur emissions, they should receive particular attention in the new scenarios. Industrial sources could be included in the scenarios with much a simpler driving force model, e.g. coupling to industrial output.)
Ceteris paribus, highest sulfur emissions occur in scenarios of high demand growth, rapid resource depletion, limited technological change and absence of sulfur control policies outside OECD countries. In terms of energy supply structures such scenarios imply a massive use of coal, including synfuel production. Typical examples would include the IS92e and IS92f scenarios. Up to ca. 2050 sulfur emissions in such scenarios roughly grow in line with fossil fuel use and resulting carbon emissions, i.e. a roughly constant sulfur to carbon emissions ratio. Post 2050, still in absence of sulfur control policies, growth rates of sulfur emissions start to fall short of growth in fossil fuel use due to the internal technology logic of synfuel production: synfuel production requires prior coal conversion (e.g. gasification) and removal of sulfur prior to further conversion, e.g. to synliquids. Ceteris paribus, therefore sulfur emissions relative to those of carbon decline.

Sulfur emissions are lower in scenarios with 1. lower demand, 2. more ample resource availability (especially for natural gas), 3. higher rates of technological change (especially for non-fossil energy technologies), and 4. extent and timing of direct sulfur control policies especially outside OECD countries (itself function of projected impacts like acidification), and finally, 5. level of other environmental control measures and valuation of environmental goods (e.g. sulfur emissions are also lower in scenarios imposing limits on GHG emissions).

Next to environmental impacts and policies, there are also other key relationships that need to be considered for the formulation of future sulfur scenarios. For instance, the literature on environmental Kuznets curves (cf. e.g. World Bank, 1992, or IIASA-WEC, 1995) argues that with increasing affluence and valuation of environmental goods, sulfur emissions decline. This hypothesis is corroborated by both longitudinal and cross-sectional empirical data. Thus, in the process of industrialization and economic development, emissions rise initially, pass through a maximum (say at income levels around 2000 $/capita) and decline thereafter with rising per capita incomes

and the resulting preference of cleaner end-use fuels, valuation of clean
environments, etc.

A scenario taxonomy along the dimensions of demand, resource
availability, and technological change in any case is necessary to
respond to the critique on the IS92 series that these important
driving forces were not varied appropriately to reflect both
uncertainty as well as new scientific knowledge and empirical
evidence.  They form part of the overall scenario design process and
the scenario ``storylines'' and need not to be addressed
specifically in the work on sulfur emissions.

Separate ``sulfur stories'' could be developed in addition, based on various
relationships between sulfur emissions and levels of affluence,
industrial structure, etc. within the overall framework of the
scenario ``storylines''.  Here sulfur emissions would be part of
other environmental policies (e.g. on water quality, urban traffic
related pollutants, etc.) that form integral part of particular
scenario ``storylines''.

A key variable remains the timing and extent of sulfur control
policies to be assumed for the new scenarios.  First of all the
scenarios need to reflect changes in actual policies implemented.
As noted above, IS92 did not take full account of recent
environmental legislation in both North America and the second
European sulfur protocol.  Secondly, the sulfur policies to be
assumed, need to reflect recent scientific findings, in particular
the very large local and regional impacts on agricultural crops and
ecosystems of unabated high sulfur emission scenarios, particularly
in Asia.  Therefore, all scenarios should assume faster and
deeper reductions in sulfur emissions outside OECD countries than
were assumed for IS92 in light of this recent scientific evidence.  The
exact timing and extent of such sulfur reduction measures could then
be scenario dependent. Also no specific reference to individual
policy measures would need to be made (to avoid normative policy
elements, or recommendations, in the scenarios), as reduction
profiles could be adopted from existing sulfur reduction scenarios
in the scientific literaursement by UE (Action COST) for the lecturer, but for this I hope to
>have an answer as soon as possible.
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>Thank you for your answer
>
>Best regards
>
>I'm Bernardo Gozzini and I work with Marco Bindi in the organisation of this
>seminar because Marco in the next week will leave for USA for two months and
>he cannot follow it
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