Tyndall°Centre
for Climate Change Research

Linking air pollution with climate change

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Technical Report 53

Linking air pollution with climate change:

Tyndall Centre Technical Report 53

This is the final report from Tyndall research project T3.14. The following researchers worked on this project:

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OVERVIEW

Most research to date has considered trans-boundary atmospheric pollution and climate change separately, even though they share many common drivers and methods of mitigation. There is a particular dearth of work in the UK on these linkages. Such work is important because (i) synergies and pitfalls in policy terms may be identified, and (ii) cost-effective strategies may be devised which distribute emission abatement efforts between pollutants and countries in such a way as to deliver on both greenhouse gas mitigation and air pollution reduction targets. This project seeks to develop the ability of the Community Integrated Assessment System (CIAS) being developed at Tyndall to model the interactions between climate and air pollution policies.

Its objectives were to exchange information on modelling approaches with the International Institute of Applied Systems Analysis (IIASA) in Austria who are experienced in air pollution modelling, to devise a new methodology to prepare for CIAS to incorporate the IIASA work on long-range transboundary air pollution on a country-specific basis, and specifically to develop foundations for a new dynamic module simulating technical choice and fuel switching on a country by country basis to allow joint simulation of greenhouse gases and air pollutants.

The information exchange showed that IIASA's approaches were so fundamentally different from Tyndall's that joint work, or direct linkage with RAINS modules, were not feasible on the short 2-person month timescale of the project, which was therefore merged with ETech Tyndall project IT1.19, and its aims re-directed towards enhancing the work of ETech in allowing the global economic model E3MG, a key component of CIAS, to simulate emissions of methane and black carbon, since emissions of sulphur dioxide, oxides of nitrogen and volatile organic compounds were already adequately covered.

This 2-person-month project derived an estimate for the coefficient for unit methane emissions from various fossil fuels. Secondly, it provided estimates of black carbon emissions from a small number of key technologies in the six fuel sectors treated in the economics model, E3MG. The project focused on black carbon emissions in China, which is responsible for approximately a quarter of global anthropogenic emissions due to its high usage of coal and biofuels.

This project has improved the simulation of methane emissions in the economic model, E3MG, and has taken one step towards enabling the E3MG model to simulate the emissions of black carbon and primary particulate matter. When BC and PM emissions are available from E3MG they will enable policy questions relating to the enhanced use of diesel relative to petrol as a transport fuel (a potential method to reduce CO2 emissions from the transport sector) to be addressed, taking into account the radiative forcing and health implications of BC and PM emissions.

Through the project the first steps were taken towards the joint modelling of air pollution and climate within the CIAS integrated assessment model being developed under the theme 1 flagship project. Ultimately this will enable CIAS to examine the interactions between climate and air pollution policy on an international scale.

TECHNICAL REPORT

Abstract

Trans-boundary atmospheric pollution and climate change have traditionally been researched separately, whilst synergies and pitfalls in policy terms may be identified if the two are considered together. This project sought to develop the ability of the Tyndall Community Integrated Assessment System (CIAS) to model the interactions between climate and air pollution policies through an exchange of information with the International Institute of Applied Systems Analysis (IIASA) and through the development of foundations for a new dynamic module simulating technical choice and fuel switching on a country by country basis to allow joint simulation of greenhouse gases and air pollutants. The IIASA approaches proved too different from those of Tyndall to move forward on new module foundations, so the project was merged with ETech (IT1.19) and refocused on improving the treatment of air pollutants in the economic model E3MG, a component of CIAS. The project derived an estimate for the coefficient for unit methane emissions from various fossil fuels. Secondly, it provided estimates of black carbon (BC) emissions from key technologies, focusing on China which emits 25% of global BC emissions. This has taken a step towards enabling the simulation of BC and other particulate matter (PM) emissions and hence towards the analysis of policy options which may reduce carbon dioxide emissions whilst increasing PM emissions which influence radiative forcing and have human health implications.

Objectives

In this project, we proposed to lay the groundwork for the development of an integrated assessment modelling system to examine potential future climate change (CC) and long-range trans-boundary air pollution (TAP) levels in Europe within the same framework. CC and TAP policies interact strongly in a number of ways, most notably through technological choice and fuel switching which affect emissions of greenhouse gases such as carbon dioxide (CO_2) and methane, (CH_4) and air pollutants such as sulphur dioxide (SO_2), nitrogen oxides(NO_x) and volatile organic compounds (VOC). Other interactions exist through atmospheric chemistry – for example because NOx and VOCs produce ozone, a greenhouse gas in the troposphere, and because SO2 becomes oxidised to form sulphates which have a negative radiative forcing.

Most research to date has considered trans-boundary atmospheric pollution and climate change separately, even though they share many common drivers and methods of mitigation. There is a particular dearth of work in the UK on these linkages. Such work is important because (i) synergies and pitfalls in policy terms may be identified, and (ii) cost-effective strategies may be devised which distribute emission abatement efforts between pollutants and countries in such a way as to deliver on both greenhouse gas mitigation and air pollution reduction targets.

To achieve this is it necessary to link an existing integrated modelling system for climate change, as exemplified by the Community Integrated Assessment System (CIAS) model being pioneered under the Tyndall Centre's theme 1 research and regional integrated assessment models for trans-boundary air pollution, such as RAINS (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/) and RAINS-ASIA (http://www.iiasa.ac.at/Research/TAP/rains_asia/docs/rains.asia.html). It is within the economics and energy modelling that this linkage is most appropriately made, due to the common emission scenarios. Therefore this project makes a perfect complement to supplement the Tyndall project ETech+: Technology policy and technical change, a dynamic global and UK approach (Anderson et al., 2005).

Our original objectives were:

a). For the consortium to achieve a mutual understanding of approaches to energy modelling associated with the RAINS model at IIASA and those carried out by Imperial College Centre for Energy Policy and Technology, and to review existing approaches to the joint modelling of air pollution and climate change.

b). To devise a new methodology for extending the existing CIAS integrated assessment modelling system to incorporate a module that treats long-range trans-boundary air pollution on a country specific basis, the RAINS TAP module. The methodology will be applicable to both RAINS-EUROPE and RAINS-ASIA.

c) To develop the foundations for a new dynamic module, DETA, (Dynamic Extension to Trans-boundary Air Pollution) simulating technical choice and fuel switching on a country by country basis, which will form the cornerstone of Tyndall's ability to link climate change policies with emission scenarios for SO2, NOx and primary particulate matter (PM) as well as greenhouse gases.

Work undertaken and Results

Objective (a)

Our aim was to share energy modelling experiences with the International Institute of Applied Systems Analysis (IIASA) in Austria. (IIASA had done much of the modelling work for the Special Report on Emissions Scenarios, led by Dr. Nakicenovic). Meetings were held in Vienna in January 2004 at which time a full exchange of experiences was obtained. A second workshop had been planned for the late Spring 2004, but this was felt to be unnecessary since IIASA had wrapped up their climate change modelling work on a global level, and were in the throes of recalibrating their RAINS-Europe model to include a full range of greenhouse gas emissions; this is, of course, important work, but not concerned with the macro-economic modelling of responses to climate change on the lines discussed above. For this reason, we decided to redirect the research under the supplementary grant to complete our efforts on the modelling and estimation of parameters for a range of greenhouse gases and local pollutants.

IIASA and ICCEPT present below their recent advances in (i) joint modelling of air pollution and climate and (ii) dynamic modelling of technical change.

Progress at IIASA

Progress at IIASA includes a plan to extend RAINS to consider renewable energy in India and China, and an extension of the RAINS energy projections to 2030, by fuel use per sector. Information from Asia has been provided from governments. China is handled at the province level. India and China have been studied internally at IIASA. Energy projections for Europe come from the model PRIMUS, which comprises a mixture of simulation and optimisation, and originates at the National Technical University of Athens, Greece. Complex country level partial equilibrium energy models exist to 2030. Data on transport was taken from Auto-Oil for Europe. Previously, work linking energy models to RAINS beyond 2010 had treated Europe only as a single region. Another key advance is that fuel substitution is now included in RAINS as an option for emission abatement. Costs and the potential for substitution come from PRIMUS. About 60 combinations of possible fuel substitutions can be considered in the power sector. Currently this methodology for fuel substitution has only been applied to the power sector and only in Europe. For Asia it is difficult to project sufficiently far into the future to continue this approach.

IIASA had already previously used the MESSAGE model (www.wgbu.de/wbgu_sn2003_ex03.pdf) to produce a realistic interpretation of non-GHG emissions for the SRES scenario B2. This is because the assessments of some of the non-GHG air pollutant emissions for SRES were extremely misleading: specifically, although the emissions of SO2 for the SRES scenarios were considered to be correct, the emissions of NOx and VOC were too high by a factor of three or four. Pollutants covered by MESSAGE are SO2, NOx, VOC, PM, black carbon (BC), ammonia (NH3), with Europe treated at the country level, Africa at the continent level, Russia as a single unit.

IIASA is now generating country level cost curves for six GHGs in Europe: CO2, CH4 are now finished and first results are available. N20-NH3 and CH4-N20 relationships are taken into account. So far CO2 and CH4 cost curves have been completed and synergies have been identified with CH4 control and agriculture: converting manure to biogas, preventing the emission of CH4.

In the RAINS model, three scenarios for future emission control of carbon dioxide had been analysed at IIASA for their costs and the co-benefits for air pollution reduction:

(a) Application of a 15% CO2 emission reduction in the European power sector subject to an exogenous energy demand, achieved through fuel substitution from high carbon fuels to cleaner fuels
(b) Achieving the same reduction in climate change by reducing another potent greenhouse gas, methane. This is called a 15% CO2 equivalent reduction.
(c) As (b) but allowing biomass to be used in domestic fuel

The results show that in scenario (a) large reductions in the emissions of SO2 occur. They also show that the costs of the CO2 emission reduction required to reduce a given amount of SO2 is actually less than the cost of reducing this SO2 by conventional Flue-Gas Desulphurisation (FGD) technology. Thus, fuel substitution is cheaper than the FGD that you would otherwise have had to install to control the air pollution. Furthermore, there are substantial health benefits associated with these reductions in SO2 emissions. In scenario (b), emission reductions are cheaper still because of the flexibility to reduce emissions of methane. The outcome is that the scenario (a) has very low costs compared to air pollution only policy to reduce SO2, and that (b) has negative costs once the benefits to human health are taken into account. The use of biomass in domestic fuel was shown to be particularly beneficial in cost-benefit terms.

A potential future collaboration with IIASA was identified through potential links between RAINS and the MAGICC (or another) climate model component of CIAS.

Progress at ICCEPT

The Tyndall Working Paper 59 "Modelling innovation & threshold effects in climate change mitigation" (Anderson & Winne, 2004) was presented at IIASA in January 2004. A potential to verify the dynamics using empirical data was identified.

Objectives (b) and (c)

Following this exchange of ideas, it became apparent that owing to the widely differing approaches and timescales for modelling being adopted at IIASA and ICCEPT, that it was not going to be feasible to develop a new methodology jointly under the small amount of funding (2 person-months) of this project. The RAINS method of calculating annualised marginal cost curves is very different from the dynamic approach being developed at Tyndall.. Furthermore, IIASA believe that it is not possible to predict with sufficient spatial detail the future distribution of fuel use in Europe so as to be able to map future emissions by country.

Thus the project was re-directed so that the link with IIASA would comprise an exchange of ideas whilst each institution would develop independent ideas about how to model air pollution emissions rather than pursuing joint work on energy projections. However, in developing our own approach we still allow for future connections to make to RAINS's atmospheric transport and deposition modules, to which a simple connection could be made with softIAM/CIAM-n project.

Having concluded that Tyndall must develop its own joint scenarios of GHG and air pollutants, the project's objective would now be to establish a method of incorporating non-GHG pollutants in the economics model E3MG, the global dynamic economic model being developed under a separate Tyndall project IT1_19 (ETech: Modelling technological change and Anderson et al., 2005) For this reason it was decided to merge the projects and hence some material appears in both project reports.

A more detailed breakdown of fuel use/sector is required to produce the air pollutant emissions than to produce the GHG emissions. Originally, the E3MG model had not provided for such a detailed treatment. The merger of the two projects led to the development of a sufficiently detailed treatment to allow an adequate treatment of air pollutant emissions in E3MG.

Extant emission data in E3MG

E3MG is a "top-down" model, so the emissions from non-CO2 gases (SO2, NOX, CH4, VOCs, N2O, HFCs, PFCs, and SF6) are modelled by inference rather than by incorporation of emission factors and activity rates as would be the case in a "bottom-up" model. The data required for the treatment of air pollutants is therefore the total annual emissions of each pollutant in each region, so that it is not necessary to work directly from the emission factors and activity rates of various pollutant-producing human activities.

(1) from each fuel user covered in E3MG, CO2 emissions from use of fuels for energy generation were obtained from the International Energy Agency (IEA) (data is available for all years, but only 1970, 1980, 1990 and 2000 were required for E3MG)

(2) from each emission source emissions of all pollutants covered by RIVM's EDGAR database were obtained for 1990 and 1995.

(3) time series data on six greenhouse gases, carbon dioxide from the energy sector from 1971 to 1995, and time series data for SO2, NOx and VOCs from 1990-1995 were also taken from EDGAR.

Hence, CO, PM, BC, lead (Pb) and chlorofluorocarbons (CFCs) were not included in E3MG prior to this project. The project focused on obtaining additional data for black carbon (BC) and in improving the estimates of methane emissions.

Work carried out through this round 3 project to model non-CO2 gases

Additional work was needed to obtain data on methane (CH4) and black carbon (BC) as not as much information has been gathered on these pollutants, and this is where this round 3 project made its main contribution. Although the EDGAR database was not able to provide any information on black carbon, a few other sources did have limited data which we explore further below.

Methane

Methane emissions come from a number of sources including transport, agriculture, biomass burning, landfills, industry, and fossil fuels. There is a good deal of uncertainty regarding the estimation of methane from some of these sources and data can be quite limited. Therefore, rather than examining all sources of methane, for now we will just focus on estimating methane emissions from fossil fuels, specifically, gas and coal.

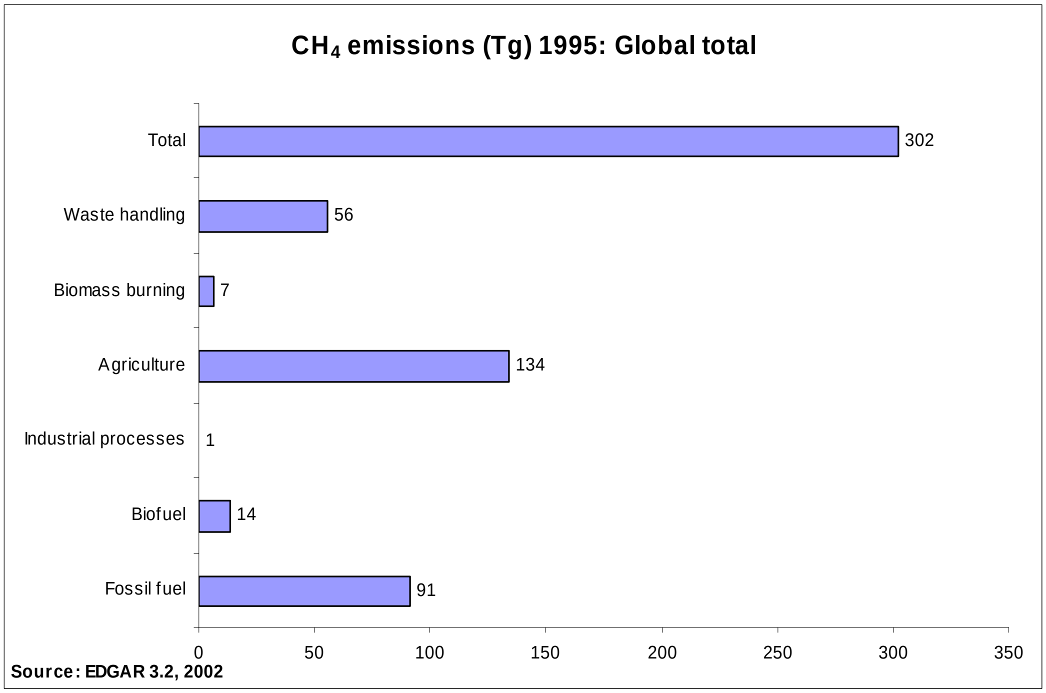
The National Institute for Public Health and the Environment (RIVM) has made available a good deal of methane emissions data from the EDGAR database. The following table gives CH_4 emissions for a number of sources for thirteen regions of the world:

Table 1: CH_4 Emissions (in Tg) in 1995.

CH4		Total	Fossil fuel	Biofuel	Industrial processes	Agriculture	Biomass Burning	Waste handling
	Global total	301.9	91.1	13.9	0.8	134.1	6.5	55.7
	Canada	5.8	2.1	0	0	1	1.5	1.2
	USA	39.8	21.5	0.3	0.1	7.5	0.2	10.3
	OECD Europe	17.4	4.3	0.1	0.1	7.7	0.1	5
	Oceanica	6.3	1.3	0	0	4.2	0.1	0.6
	Japan	2.9	0.8	0	0.1	0.4	0	1.6
	Eastern Europe	8.2	4.7	0.1	0	2.2	0	1.2
	Former USSR	36	24	0.3	0.1	7.8	0.1	3.7
	Latin America	35.1	3.4	0.5	0	21.8	2	7.2

Africa	26.7	3.5	3.6	0	14.5	1	4.1
Middle East	9.9	6	0.2	0	2.2	0	1.5
South Asia	42.3	1.9	4	0	28.2	0.1	8.1
East Asia	48.2	13.5	2.9	0.2	23.9	0	7.6
South East Asia	23.3	4	1.8	0	12.7	1.3	3.5

Figure 1:



Using this data we were able to obtain an estimate for the coefficient for unit methane emissions for fossil fuels.

Black Carbon

Data for black carbon emissions is even more difficult to find and more uncertain than data for methane emissions. Therefore total black carbon emissions from a few technologies was estimated, rather than attempting to calculate black carbon emissions from each technology in each of the six fuel sectors. We focussed on black carbon emissions in China, which is responsible for approximately a quarter of global anthropogenic emissions due to its high usage of coal and biofuels (Streets, et al., 2001). The following data was obtained on black carbon emissions in China:

Table 2.: Summary of energy and emission estimates in China by sector and fuel type
(Streets, et al., 2001)

Sector	Fuel	Energy use (PJ)		BC emissions (Gg)	
		1995	2020	1995	2020
Residential	Coal	3872	4848	605.4	534.8
	Oil	432	2088	1.0	5.5
	Biofuel	7939	6016	512.0	386.8
	Subtotal	12, 243	12, 952	1118.4	927.1
Industry	Coal	13, 171	18, 257	82.5	80.6
	Oil	2040	2513	11.1	14.5
	Biofuel	600	482	3.6	1.4
	Subtotal	15, 811	21, 252	97.2	96.5
Power generation	Coal	10, 080	18, 054	1.5	0.1
	Oil	731	607	6.1	4.8
	Biofuel	89	226	0.7	0.5
	Subtotal	10, 900	18, 887	8.3	5.4
Transport: road	Gasoline	1208	4047	2.3	7.6
	Diesel	508	2798	13.3	73.3
Transport: other vehicles	Gasoline	100	139	0.2	0.3
	Diesel	764	1644	20.0	43.1
	Coal	234	277	3.2	3.7
Transport: ships	Diesel	138	328	3.6	8.6
	Heavy fuel oil	87	308	0.8	2.7
	Subtotal	3039	9541	43.4	139.3
Field combustion	Crop residue	N/A	N/A	74.7	56.1
Total		41, 993	62, 632	1342.0	1224.4

Thus we obtained an estimate for the coefficients for unit black carbon emissions for dirty coal and biofuel in the domestic sector. Although we have only estimated black carbon emissions from biofuel and coal use in the domestic sector, they are indeed the most significant source of black carbon emissions. It would be useful to obtain similar estimates from other developing countries, such as India.

Relevance to Tyndall Research strategy

The project has enabled the CIAS integrated assessment framework to be able to provide more accurate responses of methane emissions to carbon taxes as applied in the E3MG economic component of CIAS, and has provided information necessary to produce estimates of black carbon emissions. When BC and PM emissions are available from E3MG they will enable policy questions relating to the enhanced use of diesel relative to petrol as a transport fuel (a potential method to reduce CO_2 emissions from the transport sector) to be addressed, taking into account the radiative forcing and health implications of BC and PM emissions.

Potential for Future Work

1. To complete work enabling E3MG to simulate emissions of BC and also PM, eventually allowing the effects of air pollution policies to reduce BC or PM upon climate change to be evaluated within CIAS, or similarly the effects of climate mitigation policies upon emissions of BC and PM and hence potential radiative forcing and human health implications.

2. To link the RAINS models for Europe and Asia with the CIAS integrated assessment model via the emission outputs from E3MG, to allow implications of climate policies in Europe and Asia for SO2 emissions and environmental impacts to be assessed and similarly to allow implications of air pollution policy for radiative forcing by SO2 to be explored. In general, to understand the implications of air-pollution-only policy for climate change, and of climate change policy for air pollution, and to simulate efficient joint policies.

Relevance to Tyndall Research Strategy and Flagship Project

The first steps were taken towards the joint modelling of air pollution and climate within the CIAS integrated assessment model being developed under the theme 1 flagship project. Ultimately this will enable CIAS to examine the interactions between climate and air pollution policy on an international scale.

Conclusions

This small two-person-month project has succeeded in two main aims

(a) to exchange information and share energy modelling experiences with IIASA, and to discuss the joint modelling of future emissions of CO2 and air pollutants, thus creating an intellectual bridge between those constructing the RAINS model for long-range transboundary air pollution and those constructing the E3MG model and CIAS integrated assessment modelling framework in the Tyndall Centre
(b) to assist the future development of E3MG in broadening its ability to model non-CO2 gases through scoping out the data on methane and black carbon emissions.

Methodological development work however, could not be delivered from this project alone and the project was therefore merged with the ETech project Tyndall IT1.19 since it was found that the IIASA and ETech modelling approaches were too disparate for a direct linkage to be constructed as had originally been envisaged.

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The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

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