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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	✓

Executive Summary

This report describes the methodologies used to generate NO_x and SO_x deposition and agricultural land-management scenarios for use in the Euro-limpacs project, and initial results at month 18. To calculate NO_x and SO_x deposition it is necessary to first calculate NO_x and SO_x emissions, and this is the subject of this report. Specifically, a method to determine the adjusted energy-system necessary to meet a target of 450 ppm of CO_2 in the atmosphere by 2100 is presented based on coupling the FAIR, IMAGE 2.2 and GET models. The method incorporates changes to the energy-system necessary to conform to the Kyoto Protocol and the EU Directive on Renewable Energy and considers the four images of the future proposed by the IPCC. Preliminary results indicate that to achieve the atmospheric CO_2 target, in both OECD Europe and Eastern Europe, the energy-system must move from a system currently dominated by coal, oil and gas to one more dependent on 'non-thermal' energy: solar, wind, geothermal, other renewable and nuclear. Emissions of NO_x and SO_x are predicted to decrease with the adjusted energy-system but sufficiently to comply with the Gothenburg Protocol. Further work is necessary to convert the NO_x and SO_x emissions into deposition; the source-receptor method is proposed and will be implemented in the next phase of work. The estimated emissions of NO_x and SO_x will then be used as input to the Decision Support System (work-package 9) and the catchment models (work-packages 4 and 6) to evaluate the impact on the soil and stream-water acidity, and the storage and retention of nitrogen.

The Climate and Land Use Allocation Model (CLUAM) was used to estimate the likely changes in land-use and management resultant form projected changes in climate, market-price and volume of production in the UK. Preliminary results indicate that the area of cereals under all non-climate-change futures is significantly lower than in the mid 1990s in the UK. This is a reflection the of yield increases that are forecast over the intervening 30-50 years. These yield increases vary between the A2 and B2 scenarios. Four catchments have been selected in the UK as study-areas were the predicted changes in land-use will be input to a catchment model of nitrogen dynamics to simulate the impacts on the storage and retention of nitrogen in the catchment soils, groundwater and stream-water.

1 Introduction

Freshwater ecosystems are already under stress from deposition inputs and land-management (Heathwaite et al., 1993). River-systems in Scandinavia, Central Europe and the northern- and western-UK are recovering currently from the acidifying effects of NO_x and SO_x deposition (Martin, 1986; Wright and Hauhs, 1991). Throughout Europe pollutants inputs (of N and P) from farming and effluent have been linked to problems of nutrient over-enrichment in rivers, lakes and wetlands (Neal, 2002; Wade and Neal, 2004; Heathwaite et al., 2005). Thus, when predicting the likely impacts of climate-change over the next 100 years, the effects of atmospheric deposition and land-management must be considered, particularly in the project's modelling effort which aims to predict how freshwater ecosystems will respond to multiple drivers of change.

Both atmospheric deposition and agricultural land-management are driven by socio-economics; the former by energy consumption for transport, industrial, commercial and domestic use, and the latter by farming policy, market-prices and production-volume. Thus, work has been done and is planned within Euro-limpacs to understand the links between the methods of power generation and CO_2, NO_x and SO_x emissions resultant from IPCC climate-scenarios, the Kyoto and Gothenburg Protocols and the EU Directive 'on the promotion of electricity produced from renewable energy sources in the internal electricity market' (2001/77/EC), and the expected changes in land-management in response to climate-change and reform of the Common Agricultural Policy (CAP).

Specifically, the aim of this work is:

1. to understand the relationships between future climate scenarios and current strategies to reduce CO_2 emissions (Kyoto), and SO_X and NO_X emissions (Gothenburg);
2. to estimate the influence of CO_2 emission control strategies on European SO_X and NO_X emissions;
3. to generate simulated time-series of deposition of SO_x and NO_x in Europe for the period 2000 to 2100 to supplement the predictions of precipitation, temperature and radiation changes from the Global Climate Models;

4. to generate simulated changes in land-management in response to predicted climate-change and CAP reform.

The predicted changes in deposition and land-management will be used as input to the modelling approaches, primarily in work-packages 4 and 6, to simulate soil and stream-water acidity, and nutrient transport and storage in catchments. The results will also be used in the Decision Support System (work package 9). In section 2 of this report, the relationships between future climate scenarios and SO_x and NO_x emissions are examined, and the future-work that is required to generate the time-series of SO_x and NO_x deposition is outlined. Section 2 is based on “Effects of future CO_2-reducing measures on SO_x and NO_x emissions in Europe”, a masters thesis written by Ulrika Fossum at IVL during 2005. In section 3, the methodology for determining the likely change in UK land-management in response to climate and CAP reform is described and the future work-plan described. Thus, this report is primarily a discussion document to inform the project participants of the current status of this research and the work-plans. The actual time-series of changes in deposition and land-management will be produced as part of work-package 9, tasks 1.1 and 1.2.

2 The relationships between climate policies and emission of atmospheric pollutants: SO_x and NO_x

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2.1 Introduction

The main objective of the Eurolimpacs project is to predict the future impacts of climate change on the ecological status of freshwater ecosystems. The main driver investigated is climate change itself i.e. mainly changes in temperature and precipitation amounts. This information is derived from global and regional climate models. These models are based on future predictions of CO_2 emissions from the work of IPCC and include several different scenarios which, in turn, are based on assumptions of global and regional economic development, population growth, changes in energy sources and total energy consumption.

In addition to changes in climate, ecosystems will also be affected by changes in other drivers, such as deposition of acidifying and eutrophying compounds. The future policy of SO_x and NO_x control can be more or less dependent on how the energy system will change in order to reduce CO_2 emissions. The reason is that the emissions originate from the same sources, i.e., from burning of fossil fuels. IVL has investigated how the energy systems have to change to meet the required CO_2 emission profile for a mitigation scenario consistent with policies and strategies in Europe, and how these changes affect emissions of air pollutants (SO_x and NO_x) in Europe until year 2100. In this milestone report, the relationships between future climate scenarios and SO_X and NO_X emissions are described. The results in this study will be the basis for the estimation of deposition scenarios for NO_X and SO_X in European regions in the year 2100. The calculated emissions of SO_X and NO_X from the energy systems scenarios in this study are compared with results from other scenarios.

2.2 Short description of scenarios and models

To be able to calculate the SO_x and NO_x emissions, energy systems scenarios have been constructed.

2.2.1 IPCC Scenario Storylines

In the Special Report on Emissions Scenarios (SRES) by IPCC, four storyline-based scenarios were drawn to predict future energy demand, fuel use, population growth, economic development, level of environmental care etc. These scenarios do not include additional climate initiatives. This means that no measures for reducing the CO_2 emissions are included in the scenarios. Emissions of greenhouse gases (GHG) are affected by non-climate change policies for other purposes, e.g. air quality. However, government policies can, to various extents, influence the GHG emission drivers such as demographic change, social and economic development, technological change, and pollution management. These influences are reflected in the four storylines, A1, A2, B1 and B2, which are differentiated according to the degree of globalisation and set of values (see Table 1) (IPCC, 2001).

Table 1 *The characteristics of the IPCC scenarios*

	A1	**A2**	**B1**	**B2**
Population	Stabilising population (9 billion in 2050) ⤴	Growing population (13.5 billion in 2100) ↗	Stabilising population (9 billion in 2050) ⤴	Growing population (10.5 billion in 2100) ↗
Energy intensity	↘	↗	↘	↘
Renewable and Clean technology use	↗	→	↗	↗
Other characteristics	Global	Regional	Global	Regional
	Material/economic		Environmental/Social	

The emissions of CO_2 in Europe for the four baseline scenarios differ substantially. The energy intensive A2 scenario results in the highest CO_2 emissions while more environmentally focused scenarios such as B1 and B2 result in much lower emissions.

2.2.2 CO_2 mitigation scenario

The CO_2 mitigation scenario used in this study is called S550e, which represent the required CO_2 emission profile for achieving a stabilisation of the CO_2 equivalent concentration at 550 ppm in 2100. The CO_2 equivalent profile also includes a CO_2

only emission profile resulting in a stabilisation of the CO_2 concentration at 450 ppm. The S550e scenario is therefore in this report referred to as the 450-ppm scenario.

2.3 Models

To predict the consequences in e.g. primary energy, the scenario storylines have to be implemented in a model. There are a number of different models, most of them are quite similar in structure but there can be differences in terms of investment costs, energy resources, regional data etc. One scenario storyline could lead to a large number of feasible emission pathways. The models can be run with a business as usual scenario, meaning no restrictions on CO_2 emissions, or by a specific target for e.g. the CO_2 concentration by the end of this century. There are also differences in which regions and time scales the models cover.

Even though a lot of models have been used e.g. in the IPCC reports, a shortage of sources for supply of primary data was experienced during this work. The models used for these long-term energy scenario predictions are often highly aggregated in terms of geographical regions and industrial/energy sectors. It is thus often not possible to extract data on countries, regions or energy use in specific sectors. However, the IMAGE 2.2 and the FAIR model developed by RIVM (2004) and the GET model developed at Chalmers University of Technology (the Department of Physical Resource Theory) (Azar et al., 2004) were found to provide suitable data and information for this study.

2.3.1 The IMAGE Model

The Integrated Model to Assess the Global Environment (IMAGE) 2.2 is an integrated, dynamic model for simulating the global system by determining the environmental consequences of socio-economic changes (e.g. population growth, economic and technological development) for land-use, energy use, emissions, climate, sea-level rise, ecosystems and food security. In the IMAGE 2.2 a number of submodels are included to calculate energy use, emissions, land use etc. In this study we have mainly used results generated from the submodel TIMER (RIVM, 2004a).

The IMage Energy Regional (TIMER) model simulates the demand of energy and the production of electrical energy by submodels. The emissions into the atmosphere from energy and industrial processes are calculated in the TIMER emission model

(TEM). The TEM computes regional emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile compounds (NMVOC), and sulphur dioxide (SO_2).

IMAGE 2.2 is a global model but is divided in 17 world regions (see Table 2) for which results can be obtained. The model is based on a vast amount of historical data for the years 1970-1995, and makes projections towards the year 2100. For the near-time period 2010-2020, the emissions of SO_x and NO_x in OECD countries follow the UNECE Gothenburg protocol, but only minor differences in the scenario assumptions are assumed until 2010. The implementation of the IPCC scenario storylines in IMAGE 2.2 with focus on future energy scenarios and emissions of SO_X, NO_X and CO_2 are used in this study.

Table 2 *Regions for Europe in the IMAGE and FAIR model* (IMAGE, 2001; RIVM, 2004b)

OECD Europe	Andorra, Austria, Belgium, Denmark, Finland, France, Germany, Gibraltar, Greece, Holy See (Vatican City State), Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Svalbard and Jan Mayen, Faroe Islands, Sweden, Switzerland, United Kingdom
Eastern Europe	Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Republic of Romania, Slovenia, Slovakia, Yugoslavia

2.3.2 The FAIR Model

The FAIR model (Framework to Assess International Regimes for differentiation of future commitments) is a decision-support tool that extracts information from more complex models (e.g. the IMAGE model) such as emission baselines and marginal abatement cost curves (RIVM, 2004a). For the purpose of this study the FAIR model provides information about the required reduction of CO_2 emissions compared to the IPCC baseline scenarios in the IMAGE 2.2 model.

2.3.3 The GET Model

The GET model is based on the IIASA/WEC C1 scenario (Nakicenovic et al., 1995). It is a global energy model, which means that no regional data are available from the model. The energy model consists of three parts: supply, demand and an energy conversion system (Azar et al., 2004). In this study, results from the GET model have been used to assess the maximum potentials of various energy sources.

2.4 Baseline scenarios (no CO_2 reducing measures)

To generate scenarios about future energy systems and emissions of SOx and NOx, data from The Integrated Model to Assess the Global Environment (IMAGE 2.2) implementation of the IPCC Scenario storylines have been used. The IMAGE 2.2 model supplies data about future energy use, CO_2 emissions and NOx and SOx emissions for Europe when no CO_2 reducing measures are applied. Model data for these baseline scenarios acts as a reference for the CO_2 mitigation scenarios.

2.5 CO_2 emission profiles for the 450-ppm scenario (CO_2 mitigation)

In this section the construction of a mitigation scenario for Europe for each of the four IPCC storylines are presented. The construction has been performed with data from the IMAGE 2.2 and the FAIR model.

The CO_2 emissions profiles for the 450-ppm scenario are similar for all four IPCC storylines due to assumptions on when regions in the world are supposed to participate to reduce the CO_2 emissions. However the magnitude of the reduction to achieve the target concentration, and thereby also the change and structure of the energy system, will differ between the scenarios.

The information extracted from the FAIR model is the reduction demands required to achieve the CO_2 concentration target by year 2100. The reduction profile is given as CO_2 equivalents, which means that it also includes other greenhouse gases such as methane and CO. The emissions of other greenhouse gases are thus recalculated to the amount of CO_2 that would be required to give the same contribution to the greenhouse effect. However, this study only focuses on changes in the energy systems and the greenhouse gas emission from the energy sector is dominated by CO_2. The emissions from industrial, natural and land-use sectors are held constant in the mitigation scenarios (compared to the reference scenario) and therefore the reduction factors are only applied on the CO_2 emissions.

2.6 The adjustment of the energy systems to match the CO_2 emissions profile

To be able to calculate the future emissions of NOx and SOx in Europe the energy systems for the mitigation scenario have to be determined. This has been done by starting from the energy systems in the baseline scenarios (no CO_2 mitigation) obtained from IMAGE 2.2 and then adjust them so that the CO_2 emissions follows the emission profile for the 450-ppm scenario.

The adjustment of the energy system, to fulfil the CO_2 reduction and cover the energy demand, has been made by the following assumptions (placed in order):

1. Use of heavy oil, light oil and coal were reduced and substituted by natural gas, which has a lower emission of CO_2 per energy unit. Natural gas was increased up to an extent where emissions of CO_2 from the adjusted energy system did not exceed the CO_2 emission profile of the 450-ppm scenario from FAIR. The fact that natural gas causes lower CO_2 emissions per energy output compared to oil and coal makes it a likely future policy to reduce CO_2 emissions.

2. If the energy demand was not fulfilled with only a substitution of coal and oil to gas the use of biomass was increased. The use of biomass (modern biofuels) was assumed to increased to a maximum at around 2040-2050, based on assumptions for the global GET model where biomass use reaches its maximum about 2060 (global) (Odenberger and Svensson, 2003). The maximum use for Europe is assumed to be reached earlier than for the world due to the EU directive of renewables, but also because the technology and use of biomass in the power and heat sector are already wide spread in Europe. Data for the maximum potential for biomass use was given by IMAGE 2.2.

3. The use of non-thermal electricity was used to meet the remaining energy demand not covered by fossil fuels or biomass (that is if the CO_2 emissions are maximised and the maximum potential for biomass is reached). The use of non-thermal electricity is also limited by the maximum potential given by IMAGE 2.2.

Since the energy systems have been determined without a model, the economical optimisation on fuel choice has not been considered. However, the initial energy systems from the IMAGE 2.2 are based on cost-effective options why the initial ratio between different energy sources is assumed to be correct. Also the maximum potentials for biofuels, hydropower and non-thermal electricity given by IMAGE 2.2, have been considered in the adjustment of the energy system. No increase in the use of hydropower compared to the reference scenario has been assumed due to restrictions in many areas for further extension of hydropower stations. The changes in the energy system will probably occur mainly around 2050 due to the estimated lifetime of the current power and heat plants in Europe.

The energy system and energy demand in Europe will differ between the different scenarios based on the storylines from IPCC (A1, A2, B1 and B2). The concentration of CO_2 in the atmosphere is given for the baseline scenarios from IMAGE 2.2, which, of course, depends on the global emissions of CO_2. When considering regional impacts of climate change and regional scenarios for reducing climate changes, a global system must be the base.

2.7 Energy systems for Europe

The energy sources in the energy systems shown in Figure 1 and Figure 2 are categorised according to the IMAGE 2.2 model: Non-thermal electricity (Solar, wind, geothermal, other renewables and nuclear energy), Traditional biofuels (wood, agricultural waste etc.), Modern biofuels (biogas and bioliquids). However, the use of light oil is included in the primary energy system, and the use of heavy oil is reduced accordingly, since the emissions of SO_X and NO_X from the base line scenarios are based on the use of both.

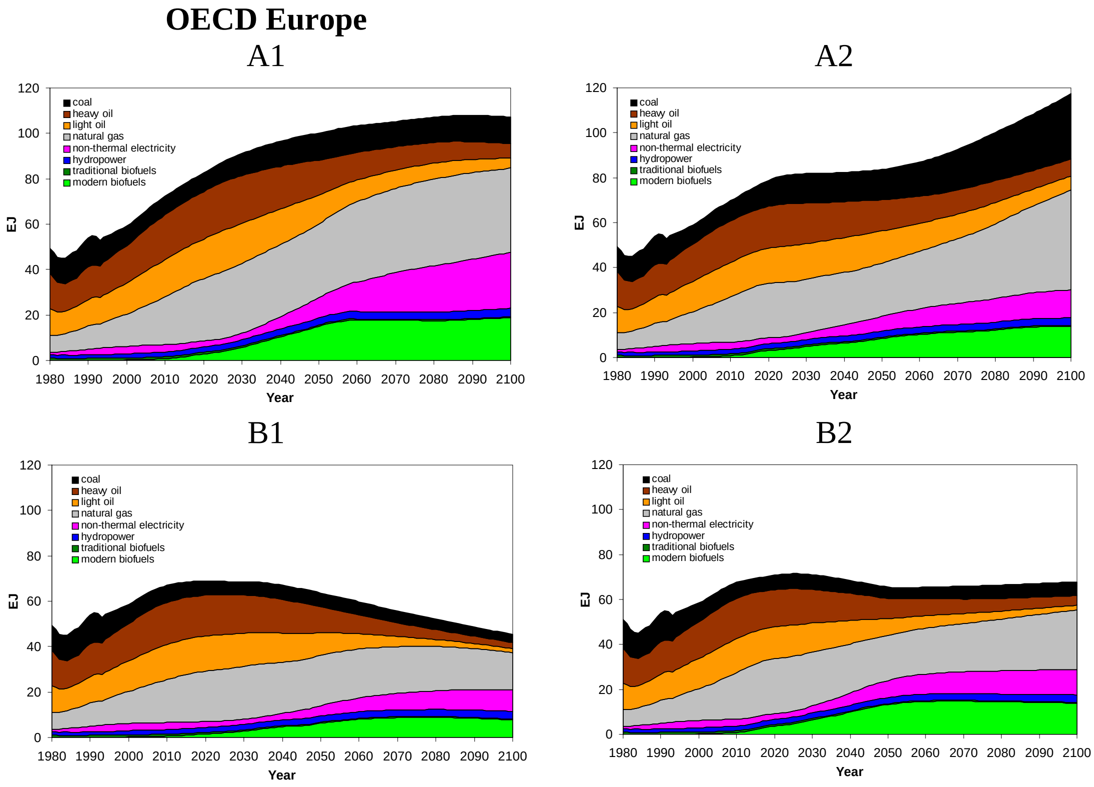

Figure 1 *Energy system for the baseline scenario representing the A1, A2, B1 and B2 scenario storyline for* *OECD Europe*, *data from IMAGE 2.2 (EJ=10^{18} J)*

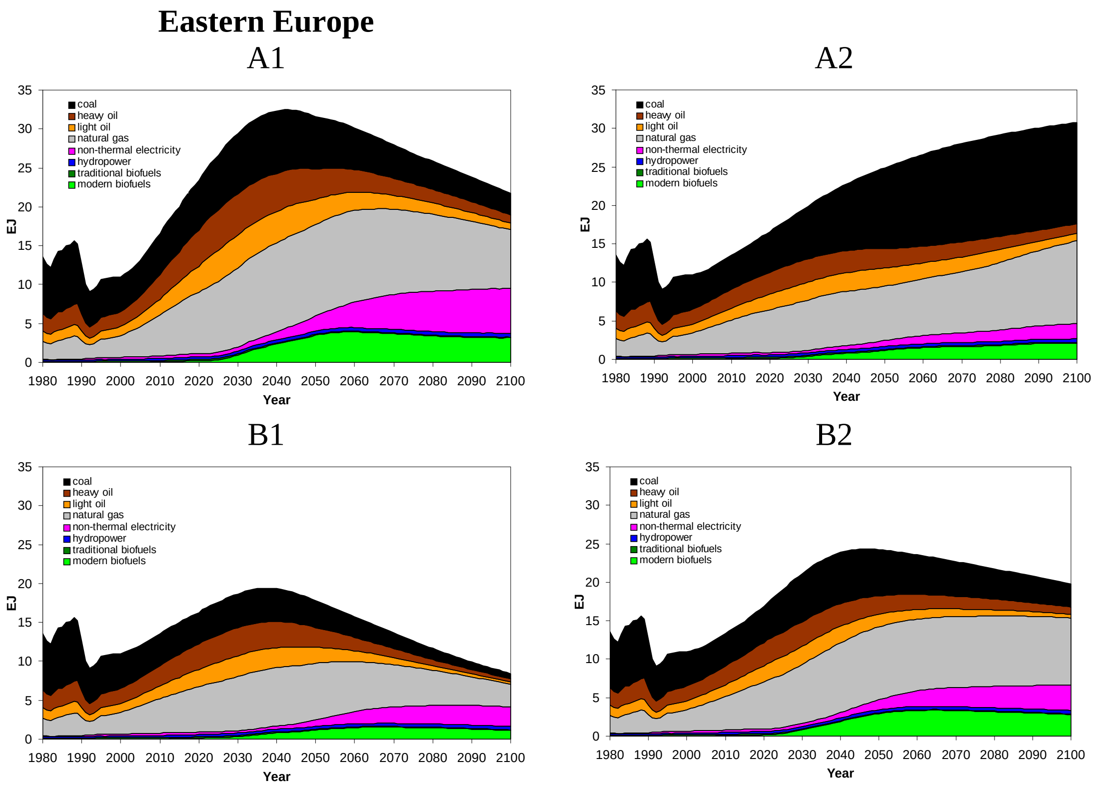

Figure 2 *Energy system for the baseline scenario representing the A1, A2, B1 and B2 scenario storyline for* *Eastern Europe*, *data from IMAGE 2.2 (EJ=10^{18} J)*

2.8 The adjusted energy system for the CO_2 mitigation scenario (450ppm)

The required CO_2 emission profiles from the FAIR model and the CO_2 emissions from the baseline scenarios are shown in Figure 3. The emission profiles for the mitigation scenario are similar for all scenario storylines due to the fact that a specific amount of CO_2 may be emitted to achieve a specific CO_2 concentration.

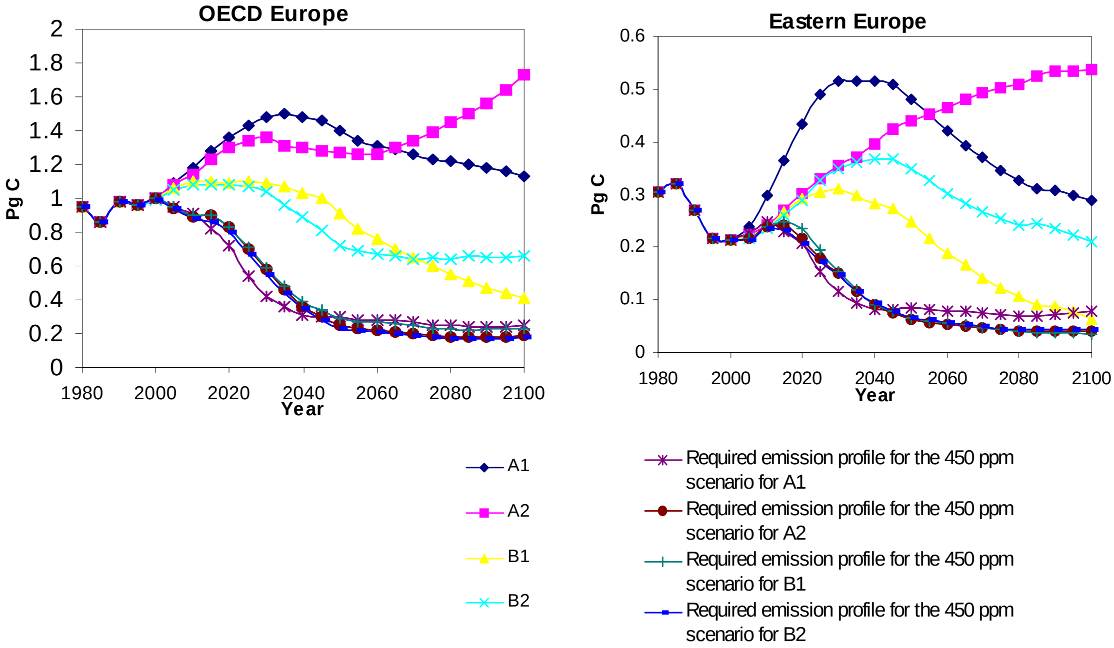

Figure 3 *Emissions of CO_2 in PgC ($P=10^{15}$) for the baseline scenarios compared to the required emission profile for the 450-ppm scenario, data from IMAGE 2.2 and FAIR*

2.9 The adjusted energy system

The adjusted energy systems that match the CO_2 emission profile for the 450-ppm scenario are presented in Figure 3 and Figure 4. The dotted line (referred to as “all”) represents the total energy demand for the baseline scenario. The total energy demand will probably be lower than what the scenarios suggest due to increased energy efficiency in order to reduce CO_2 emissions. However, energy efficiency has not been considered when adjusting the energy systems. The changes in the energy systems are of course more noticeable for the energy intensive scenarios (A1, A2) than for the more environmentally oriented scenarios (B1, B2).

OECD Europe

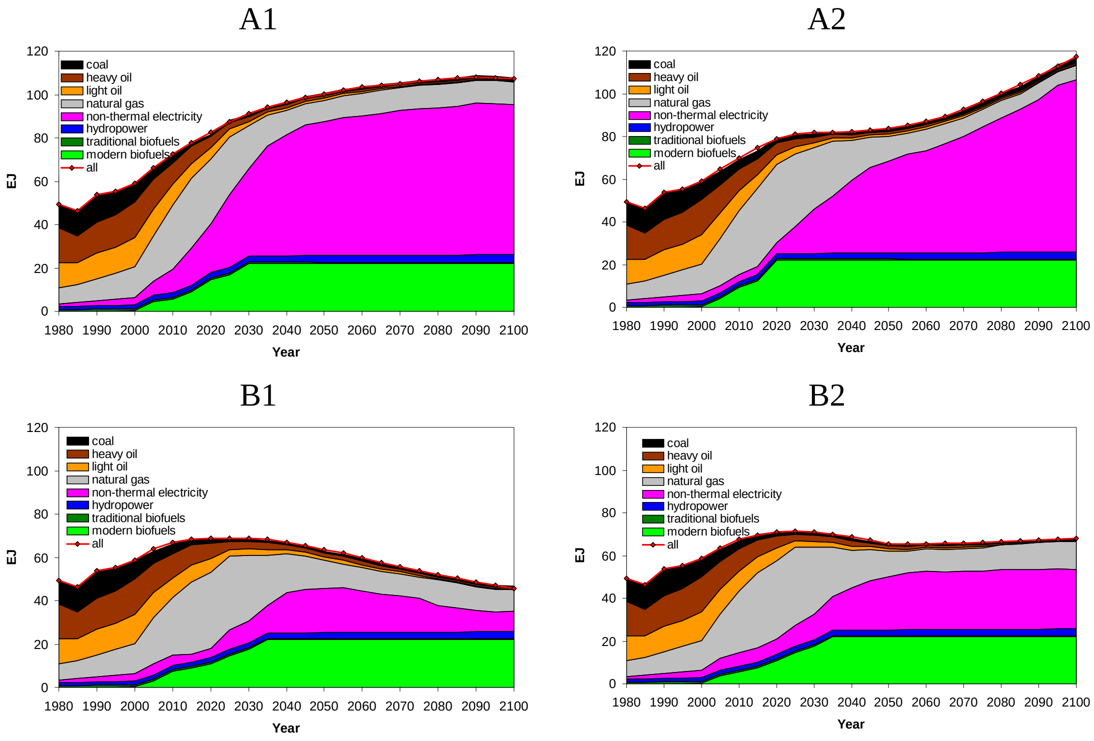

Figure 3 *Adjusted energy system for* *<u>OECD Europe</u>* *that matches the* CO_2 *emission profile of the 450-ppm scenario for the A1, A2, B1 and B2 scenario storyline*

Eastern Europe

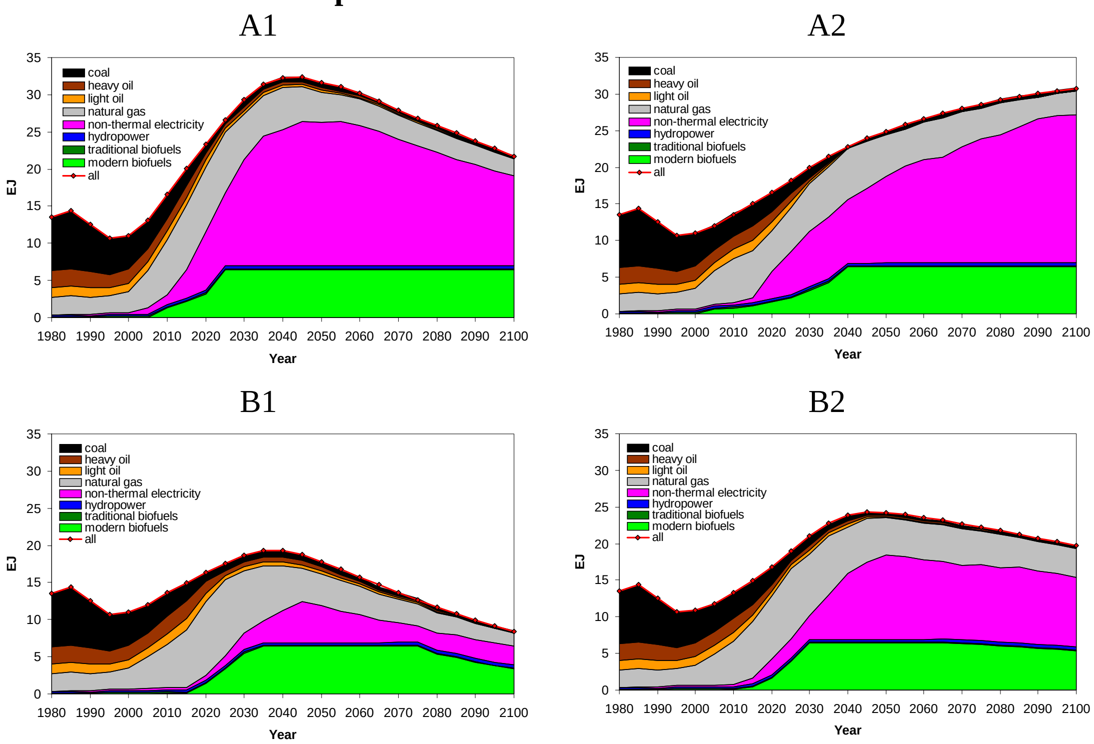

Figure 4 *Adjusted energy system for* *<u>Eastern Europe</u>* *that matches the* CO_2 *emission profile of the 450-ppm scenario for the A1, A2, B1 and B2 scenario storyline*

2.10 The SO_X and NO_X emissions

The calculation of SO_x and NO_x emissions from the adjusted energy systems for the IPCC scenario storylines are performed with emission factors calculated with data from the IMAGE 2.2. The non-abated emission factors for SO_x and NO_x are constant with time for a specific fuel and combustion technology. However, the effect and use of abatement technologies leads to changes in the emission factors. Thus, calculation of SO_x and NO_x emissions for the abatement scenario requires consideration of future changes of emission factors. In IMAGE 2.2, future changes in emission factors are considered and thus data for energy use and emissions in the reference scenario supplied by IMAGE 2.2 have been used to calculate those emission factors. By this method the emission factors used in calculation of emissions in the abatement scenario will be the same as for the reference scenario. This is a prerequisite for comparing the two cases. Thus, an emission factor for each energy carrier (I) has been calculated for a specific year (t) by equation (1). The emission from each energy carrier (I) in the abatement scenario has then been calculated for the specific year (t) by equation (2).

$$\text{Emission factor}_{I,t}\ (g/J)_{ref.} = \text{emission}_{I,t}\ (g)_{ref.} / \text{energy use}_{I,t}\ (J)_{ref.} \quad (1)$$

$$\text{Emission}_{I,t}\ (g)_{red} = \text{emission factor}_{I,t}\ (g/J)_{ref.} * \text{energy use}_{I,t}\ (J)_{red.} \quad (2)$$

The emissions are calculated in gram (g) per Joule (J).

The emission factors are calculated on the basis of the ratio of energy carrier used in different sectors in the reference scenario and the emissions of NO_x and SO_x are based on aggregated emission factors.

The emissions of SO_x and NO_x for Europe calculated from the adjusted energy systems are presented in Figure 5 and Figure 6 (for specified emissions for OECD and Eastern Europe see Figure 9 and Figure 10 in the Appendix). The emissions from IMAGE 2.2 are higher than the historical reference emissions from the EMEP database. In the case of SO_x the difference varies from 18% in 1990 up to 62% in 2000 (B2). For NO_x the differences are smaller, varying from 0.4% in 1995 to 14 –

19% in 2000. This is probably a result of the reference year used in IMAGE 2.2 (1995), but also that the model assumes higher emissions due to historical trends for emission factor improvement. For SO_x all of the scenarios indicate a substantial reduction by 2100 down to 2 TgS or less, following a similar trend over time. In contrast, the time series of the yearly emissions of NO_x obtained in the different scenarios are quite divergent. The largest difference between the mitigation scenario and the baseline scenario is obtained from the A2 scenario storyline, where the emission from the later is more than three times higher by the year 2100.

The targets for the Gothenburg protocol are not achieved for SO_x emissions from the A2 baseline scenario. The target is also not achieved for NO_x emissions from any of the scenarios within the timeframe of the protocol (the reductions should be achieved in 2012 according to the protocol).

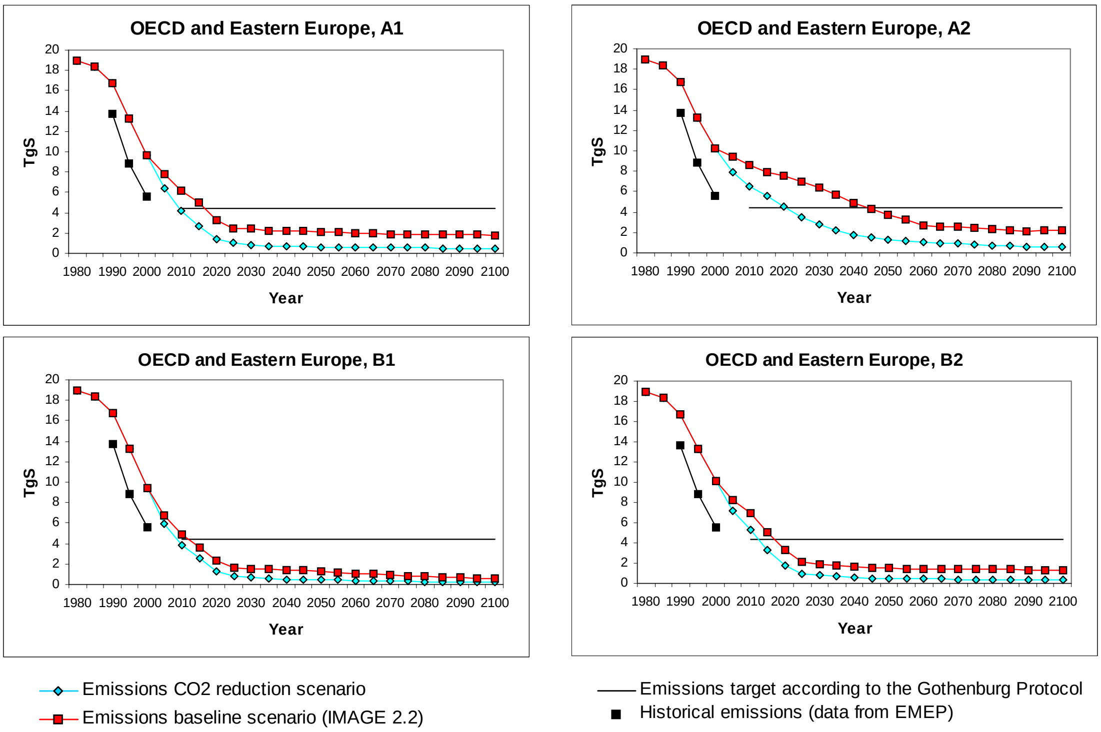

Figure 5 *Emissions of SO_x in TgS for the four baseline scenarios and for the CO_2 mitigation scenarios. The emissions are also compared with present policies according to the Gothenburg protocol, 4.38 TgS, and historical emissions from the EMEP database*

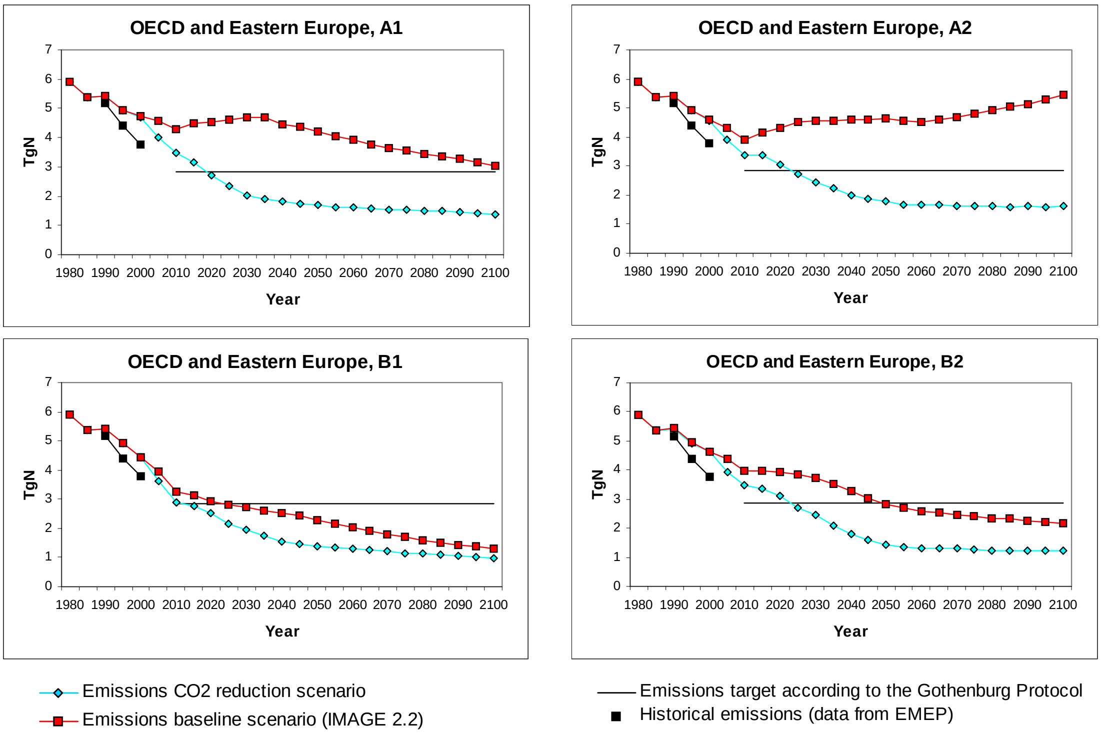

Figure 6 *Emissions of NO_x in TgN for the four baseline scenarios and for the CO_2 mitigation scenarios compared with present policies according to the Gothenburg protocol, 2.85 TgN, and historical emissions from the EMEP database*

2.11 Comparison with other scenario studies

Within the frame of the AIR-CLIM project, consistent scenarios of emission, climate change and regional air pollution to enable an integrated analysis of the linkage between climate change and regional air pollution in Europe are produced and evaluated (Mayhofer et al., 2002). The AIR-CLIM scenarios are based on the SRES IPCC scenarios A1 (B) and B1, which have been worked out in more detail focusing on the regions OECD Europe, Eastern Europe and the former USSR, with the assumption that the Gothenburg Protocol level is reach by 2010. Different combinations of greenhouse gas policy and air pollution policy have been analysed up to year 2100. The AIR-CLIM A1-550-P scenario aims at 550 ppm global CO_2 while the AIR-CLIM B1-450-P scenario aims at 450 ppm CO_2. The CO_2 reduction scenario used in this study aims at 450 ppm CO_2. Due to this difference in scenario target and the fact that the European part of the former USSR is included, the results from AIR-CLIM are not exactly comparable with the results presented here. The largest difference appears for SO_x. The A1 emission baseline scenario (Figure 7) indicates a larger and faster reduction in SO_x emission down to 1.8 TgS by 2100, as compared to the 4 TgS obtained in the AIR-CLIM A1-P scenario. P stands for present policies, i.e.

in this case compliance with Gothenburg Protocol. In the AIR-CLIM B1-P scenario the emission in 2100 is about 1.3 TgS, twice the emission in the B1 emission baseline scenario. The differences remain also when climate policy is applied. In the case of NO_x, the results are more comparable. Both the A1-P scenario and the A1 emission baseline scenario indicate an emission of 3 TgN by 2100. Applying climate policy leads to an emission reduction down to 1.4 TgN by 2100 in our study compared to 2.4 TgN in the AIR-CLIM A1-550-P scenario. The two B1 scenarios give an emission of 1.3-1.4 TgN by 2100, and about 1 TgN when CO_2 reduction is applied. In this case the target is the same for both scenarios, 450 ppm CO_2. Taken into account the differences in geographical coverage and scenario details, this comparison support the reliability of the emission estimates presented in this study.

Scenarios of world anthropogenic emissions of air pollutants and methane up to 2030 have been presented by IIASA (Cofala et al., 2004). The projected development of anthropogenic NO_x and SO_x emissions in Europe due to “Current Legislation” (CL) and “Maximum Feasible Reductions” (MFR) have been used here for comparison, see. No measures to reduce CO_2 emissions are introduced. It is anticipated that the development of energy demand within the next 30 years results in an increase of the world CO_2 energy-related of about 4.4 PgC/yr., which is in line with the SRES IPCC A1 (B) scenario. However, emissions from biomass burning, from air traffic or from international sea traffic are not assessed. In comparison with the IIASA CL scenario, the corresponding baseline NO_x emissions calculated in our study are higher, possibly due to the difference in source category coverage. Only in scenario B2 is the reduction comparable. For SO_x however, the IIASA CL scenario is in good agreement with the baseline scenario in A1, while B1 and B2 both are lower. A comparison with the IIASA MFR scenario indicates that the measures applied in this scenario are much more effective in reducing NO_x emissions than the CO_2 emission reduction measures used in our study. For SO_x the scenarios are comparable.

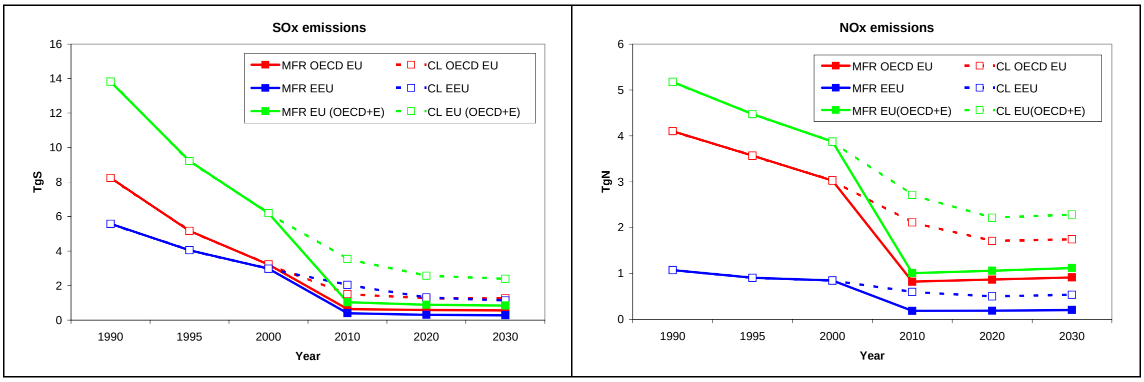

Figure 7 *Projected development of anthropogenic NOx and SOx emissions (data obtained from Cofala et al.).*

2.12 Further work

This report outlines the development of emission scenarios for SO_2 and NO_X until year 2100. These emission scenarios will be used to estimate future deposition scenarios for use in Eurolimpacs modelling and assessment.

The evaluation of emission scenarios for SO_x and NO_x is associated with considerable uncertainties. The main reasons are the difficulties associated with predicting global and regional population growth and energy demand. The models used for this in the IPCC work are, by necessity, very generalised and detailed information on e.g. energy use, fuel type, assumed technologies for energy production and pollutant control, are often not available. This lack of information probably affects the uncertainties of predictions of SO_x and NO_x emissions more than CO_2 emissions, since the levels of these pollutants will vary greatly with fuel type, emission control etc.

The following main steps in the work remain:

1. Further refinement and finalisation of energy and emission scenarios. This includes e.g. harmonisation consistency checking with the results of other studies and distribution of emissions to individual countries.
2. Calculation of deposition scenarios using available source-receptor matrices for air pollutants. This will be based on source-receptor matrices (country to EMEP grid) from modelling results of the EMEP MSC West.
3. Estimation and documentation of main uncertainties.
4. Final reporting and distribution of data.

3 Impacts of economic drivers on agricultural practices under climate change

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3.1 Introduction

The objective of this work is to translate the global pressures likely to affect land-use decisions (future climate change, & socio-economic developments, eg, developments in trade policies, economic and population growth etc.) into land-use changes at the catchment scale, feeding these conclusions into the GIS-based Decision Support System and catchment modelling.

3.2 Methodology

The objective will be achieved by means of a modelling exercise using an economic model called the Climate Land Use Allocation Model (CLUAM), which translates market-prices, policy and technology scenarios into land use changes. The sources of the socio-economic and climate scenarios are described in Table 3.

Module	Module subcomponents
The socio-economic change scenarios	IPCC SRES global futures
	UKCIP refinements of SRES for UK
	BLS world food trade model
The climate change scenarios	HadCM3 projections

Table 3. Scenarios to be used in CLUAM

Climate change is driven by socio-economic developments, so the starting point of this exercise is a forecast of future socio-economic conditions. These are derived from the latest socio-economic projections from the IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2002). Scenarios A2 and B2 were chosen as prescribed for the whole project in the Annex 1, Description of Work of the Euro-limpacs Contract.

These two SRES scenarios were used to drive the climate change scenarios. The climate change scenarios were generated using the Hadley Centre's third generation coupled Atmosphere-Ocean Global Circulation Model (HadCM3) to produce annual climate change projections for two time slices, the mid 2020s and mid 2050s. The HadCM3 climate scenarios have been used in a suite of crop models to generate changes in future yields for all global regions. These yield changes, together with socio-economic data from the two SRES scenarios, were then fed into the BLS Global Food Model developed by the International Institute for Applied Systems Analysis, Vienna. The BLS Food Model is a suite of interlinked territorially-based models forming one General Equilibrium model, used for analysing the world food trade system, in terms of (1) production volumes; (2) Market prices; (3) technology change (yields). The BLS Food Model was deployed to add sufficient detail to the largely qualitative SRES and yield change data to make them suitable for the UK-based CLUAM.

The CLUAM is a linear programming model of agriculture in England and Wales, which seeks to maximize economic total margin using various production activities to produce the range of agricultural outputs using different inputs and resources, on different types of land. The land base is partitioned into fifteen Land Classes using the ecological stratification system developed by the Centre for Ecology and Hydrology, UK.

Allocation of land to production activities is subject to three basic types of constraint:

1. The availability of different types of land within each Land Class;
2. The total volume of production and input use required;
3. Policy constraints (availability of quotas, limits to input use in designated areas, e.g. CAP, Nitrate Vulnerable Zones).

The CLUAM generates the following outputs, at the land class, regional and national level and at a catchment level for the UK catchments, Kennet, Tamar, Wye and Conwy:

1. Changes in livestock numbers and crop and grassland areas;
2. Area of land under different land types and the area falling out of agriculture;
3. Areas of land transfers (between land cover types and reflecting land improvement);

4. Change in the use of inputs, including fertilizer and chemical use per hectare and in aggregate.

3.3 Progress to date

All scenario data have been acquired including both the climate change and socio-economic data. These data have been entered into the CLUAM and two references (A2/B2 scenario runs, no climate change) and two climate change scenario runs (A2/B2) have been completed. While the reference and climate change scenario runs have been done, these have been done without making the four river catchments geographically explicit.

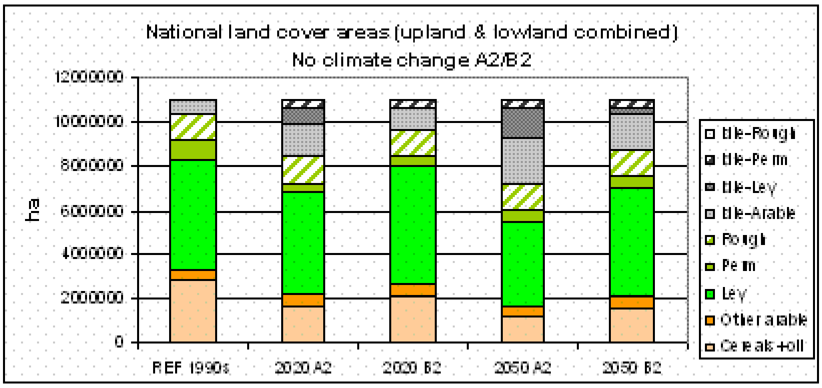

Figure 8. *Changes in the area of different land covers for both A2 and B2 scenarios in the UK (upland and lowland combined).*

Figure 9 shows the national distribution of land cover projected by the CLUAM for the A2 and B2 non climate change reference runs. By including the area of unallocated land in each scenario, the total land area recorded in each case sums to a constant 11.01 Mha. In addition to the scenario results the figure also includes equivalent areas for the mid-1990s to permit comparison of the future projections with the broadly current position. It is immediately obvious from the Figure that the area of cereals under all non-climate-change futures is significantly lower than in the mid 1990s. This is a reflection the of yield increases that are forecast over the intervening 30-50 years. These yield increases vary from scenario to scenario, according to the economic and political assumptions that underlie them. In the paragraphs that follow, the yield and demand changes for each crop under each scenario are examined as drivers of the changes observed in the figure above.

A2– NATIONAL ENTEPRISE

2020

Under this scenario, projected yield increases are relatively modest. However, cereals yield increases (+33% - wheat) still outpace demand change (no change for either wheat or barley). This leads the model to pair back the cereals area compared with the mid-1990s position. The extent of the scale back can be gauged against the other 2020 non climate change scenarios – with only the World Markets scenario posting a lower area. The loss of cereals land is largely brought about by the elimination of barley.

2050

Yield increases for the A2 2050 scenario are projected to be roughly double those of 2020. Cereals yields are forecast to rise by as much as 62%, while demand actually falls by 4%. To avoid a state of serious over-supply, the model has to reduce the area of cereals very significantly, ie, to less than half of the mid-1990s position, largely brought about by the removal of barley and oats production.

B2– GLOBAL SUSTAINABILITY

2020

The emphasis of this scenario is sustainable use of natural resources. Accordingly, yields of all arable crops are projected to decline on mid-1990s levels (for example, wheat and barley by 10%). Demand for cereals is unchanged on mid-1990s levels. Without an expansion in the cereals area these commodities would be under supplied. However, the model has limited scope to increase production area because of demand for land for the production of other enterprises. The Figure shows that the area of cereals produced nationally declines below the mid-1990s level, due to a loss of barley and oats production, but to less of an extent than for any other non-climate change scenario. There is also a move to produce cereals on higher yielding land to improve margins.

2050

This scenario, with its emphasis on sustainability, sees crop yields fall by 10% by 2020. By 2050, via technological improvement, these yields have recovered to mid-1990s levels. Demand is also, relatively unchanged on mid-1990s levels, suggesting that the area of cereals produced should be fairly similar to the mid-1990s position. However, as Figure 6.2 shows, there is a large fall in the area of cereals produced, and in large part this is driven by a loss of barley and oats production, together with a very slight reduction in demand for cereals and a move to produce cereals on higher yielding land to improve margins.

3.4 Future work

The following future is planned between 1 August 2005 and 30 November 2005.

1. Modify CLUAM to make the 4 UK catchments geographically explicit;
2. Re-run A2/B2 reference and climate change scenarios with the 4 river catchments so identified;
3. Submit outputs to the Decision Support System (work-package 9) and run land-use changes through the INCA-N model to predict the likely changes in stream-water nitrate concentrations and loads (work-package 6).

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5 Appendix

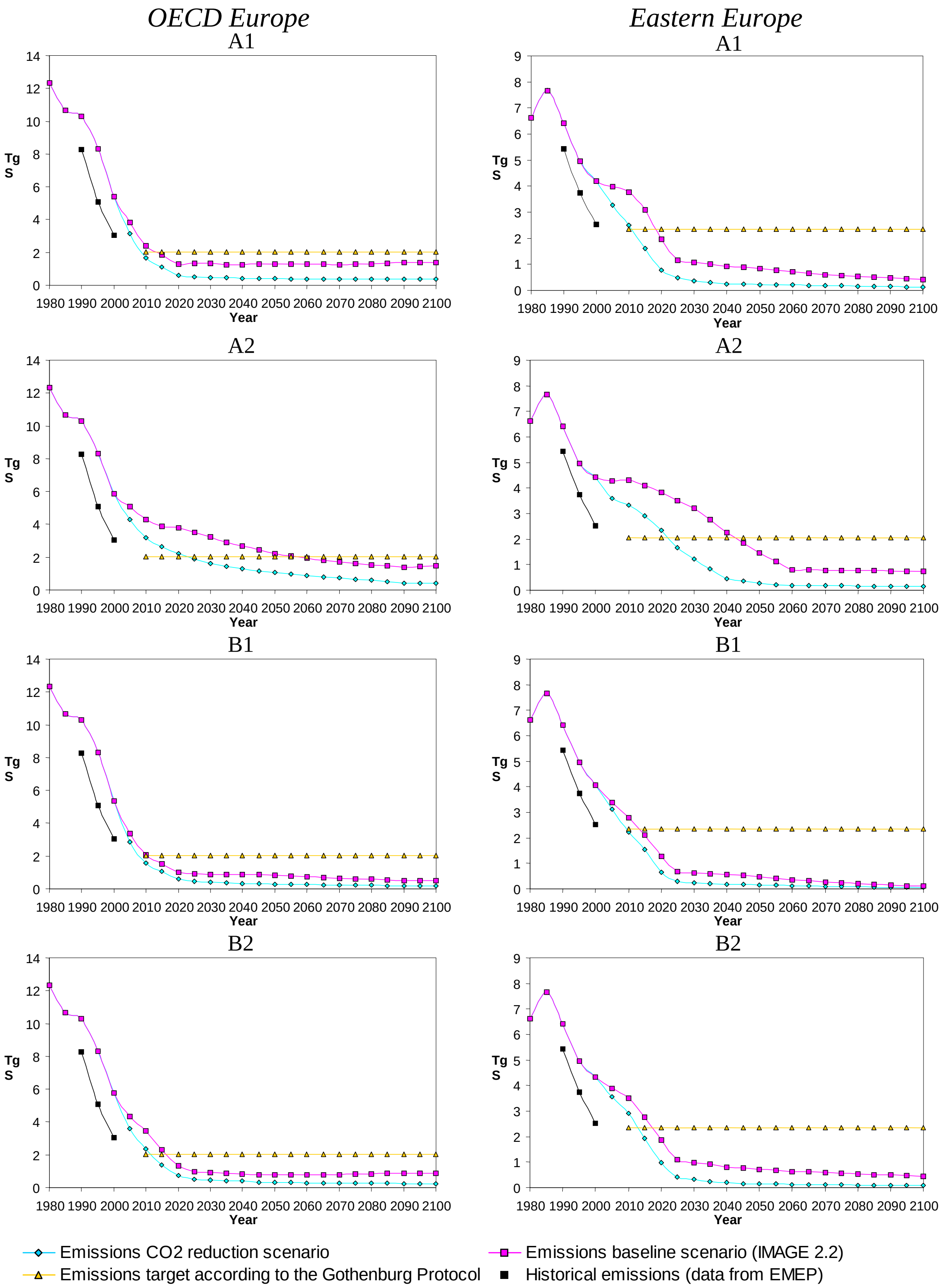

Figure 9 Emissions of SO_x for the four baseline scenarios and for the CO_2 mitigation scenarios. The emissions are also compared with present policies according to the Gothenburg protocol and historical emissions from the EMEP database

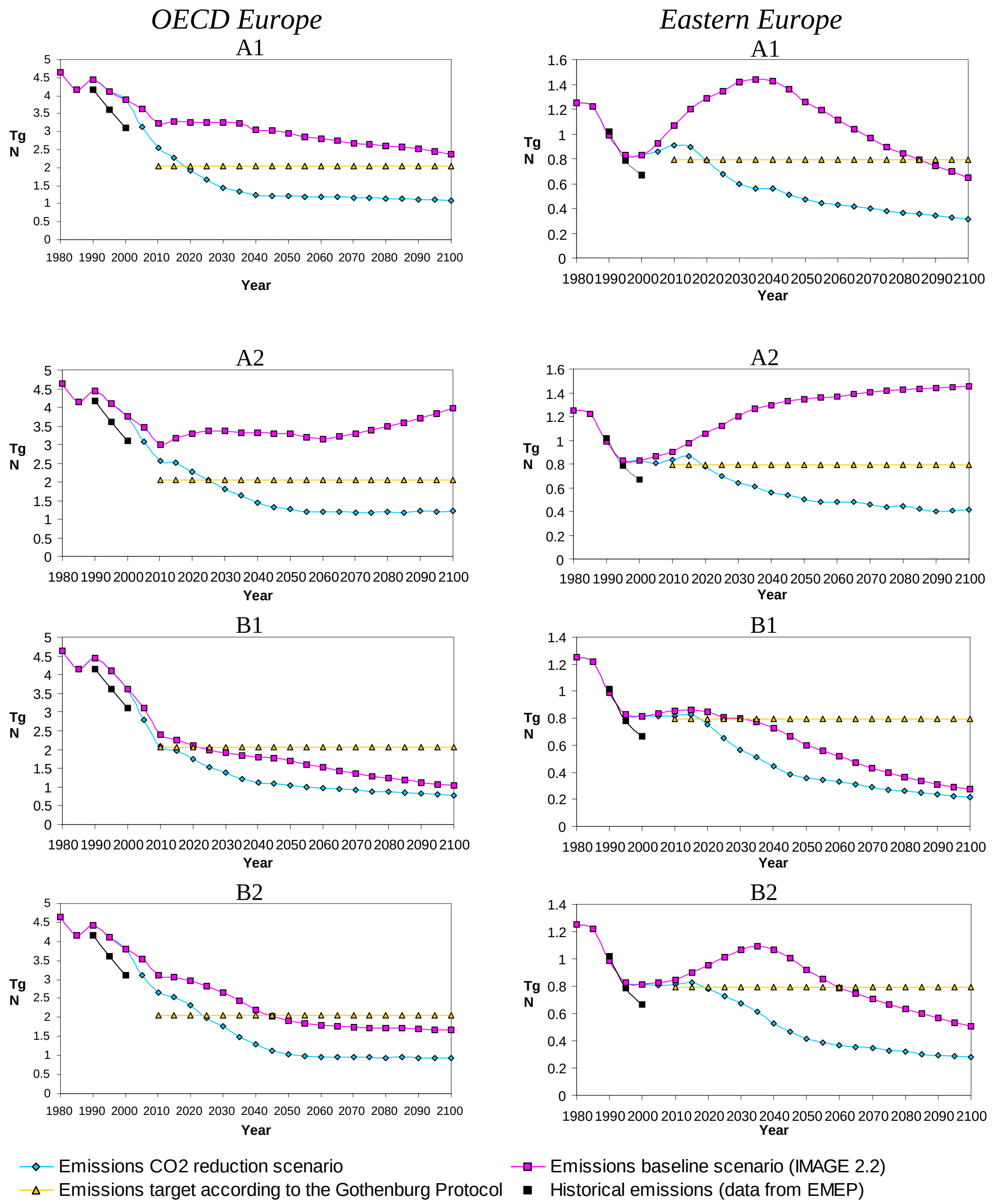

Figure 10 Emissions of NO_x for the four baseline scenarios and for the CO_2 mitigation scenarios compared with present policies according to the Gothenburg protocol and historical emissions from the EMEP database