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OVERVIEW OF IMAGE 2.0: AN INTEGRATED MODEL OF CLIMATE CHANGE AND THE GLOBAL ENVIRONMENT

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1. INTRODUCTION

This purpose of this paper is to present a brief overview of the IMAGE 2.0 model, a multi-disciplinary, integrated model designed to simulate the dynamics of the global society-biosphere-climate system (Alcamo *et al.*, 1994a). The paper emphasizes the scientific aspects of the model, while another paper in this volume emphasizes its policy aspects (Alcamo, *et al.*, 1995). The objectives of IMAGE 2.0 are to investigate linkages and feedbacks in the global system, and to evaluate consequences of climate policies. Dynamic calculations are performed to year 2100, with a spatial scale ranging from grid ($0.5^0 \times 0.5^0$ latitude-longitude) to world political regions, depending on the sub-model. A total of 13 submodels make up IMAGE 2.0, and they are organized into three fully linked subsystems: Energy-Industry, Terrestrial Environment, and Atmosphere-Ocean.

The fully linked model has been tested against data from 1970 to 1990, and after calibration can reproduce the following observed trends: regional energy consumption and energy-related emissions, terrestrial flux of carbon dioxide and emissions of greenhouse gases, concentrations of greenhouse gases in the atmosphere, and transformation of land cover. The model can also simulate current zonal average surface and vertical temperatures.

2. ENERGY INDUSTRY SUBSYSTEM

The purpose of the Energy-Industry subsystem of the IMAGE 2.0 model is to develop global scenarios of regional emissions of greenhouse gases based on future estimates of regional energy use and industrial production (de Vries *et al.*, 1994). The subsystem consists of four linked models. The Energy-Economy model computes regional energy consumption with a special emphasis on final energy consumption in end-use sectors, based on economic activity levels and energy conservation potential. The Industrial Production and Consumption model estimates future levels of industrial output in sectors that are important emitters of greenhouse gases. These two models are complemented by two other models that compute the complete range of emissions of greenhouse gases and ozone precursors, based on emission factors per compound and per activity. A wide range of emission control strategies can be specified by adjusting technological and economic variables in the subsystem of models.

For a baseline "Conventional Wisdom" scenario*, global CO_2 emissions from energy and industry increase from 6.1 Pg C a^{-1} in 1990 to 16.7 Pg C a^{-1} in 2050, and to 24.2 Pg C a^{-1} in the year 2100 (de Vries *et al.*, 1994). Global emissions of CH_4, N_2O, and CO sharply increase because of increased emissions from industrial processes. The uncertainty of baseline CO_2 estimates was investigated in a detailed mathematical analysis of parameter uncertainty of the model. Based on this analysis, the 90% confidence interval of computed CO_2 emissions (year 2050, Conventional Wisdom scenario) was estimated to be 11.3 to 24.4 Pg C a^{-1} (de Vries *et al.*, 1994).

3. THE TERRESTRIAL ENVIRONMENT SUBSYSTEM

The purpose of the Terrestrial Environment subsystem is to simulate changes in global land cover on a grid-scale based on climatic and economic factors. This subsystem also estimates the fluxes of CO_2 and other greenhouse gases between the biosphere and atmosphere. The subsystem consists of five linked models, covering agricultural demand, terrestrial vegetation, land cover, land use emissions, and terrestrial carbon flux (Figure 1).

The Land Cover model simulates land cover transformations on a global grid by reconciling the regional demand for land with the local potential for land (Zuidema *et al.*, 1994). The regional demand for land comes from demands for cropland and rangeland computed by the Agricultural Demand model (Zuidema *et al.*, 1994), and for fuelwood from the Energy Economy model (not part of the Terrestrial Environment subsystem). The potential for land is estimated by the Terrestrial Vegetation model which computes potential crop yield and potential natural vegetation based on climate and other environmental factors (Leemans and van den Born, 1994). Once land cover and its conversion rate are computed, this information is used by the Land Use Emissions model to compute the flux of methane and other greenhouse gases from land use activity (Kreileman, and Bouwman, 1994), and by the Terrestrial Carbon model to compute the flux of CO_2 from biomass burning, soil respiration, and plant productivity (Klein Goldewijk, *et al.*, 1994). Model calculations have been tested against data from 1970-90 for crop production, vegetation cover, and country-scale deforestation rates.

For a baseline Conventional Wisdom scenario, it was found that there could be very large differences in future trends in land cover changes between regions (Zuidema *et al.*, 1994). However, deforestation rates in all regions rapidly diminish after the middle of next century because demands for land stabilize or because forests are depleted. For the same scenario, the model computes that the terrestrial biosphere acts as a strong carbon sink in the 21st century because of forestation of abandoned agricultural land in the Northern Hemisphere and global feedbacks to vegetation (Alcamo, *et al.*, 1994b).

4. THE ATMOSPHERE-OCEAN SUBSYSTEM

The purpose of the Atmosphere-Ocean subsystem of IMAGE 2.0 is to compute dynamic changes in greenhouse gases and resulting changes in global temperature and precipitation patterns. The basic idea of this subsystem is to compute transient changes in climate, and to do it in a way that is computationally efficient. This is a necessary condition for an integrated model. Zonal average changes in climate are computed, and these are downscaled to a global grid using results from general circulation models. The four components of the subsystem are: atmospheric composition (Krol and van der Woerd, 1994), atmospheric climate,

ocean climate, and ocean biosphere/chemistry (de Haan *et al.*, 1994). The model has been tested against field data of atmospheric chemistry, long-term climate patterns, and data from general circulation models.
For the baseline Conventional Wisdom scenario, the atmospheric CO_2 concentration increases up to 777 ppmv by the end of the next century. By comparison, CH_4 stabilizes in the atmosphere because of stabilized emissions of carbon monoxide, a precursor compound of CH_4. Under this scenario, the average surface temperature of the world's oceans increases about 1^{0}C from 1990 to 2100. For air temperatures, the average increase in this period is 2.5^{0}C, and ranges from 3 to 5^{0}C in the northern latitudes.

5. SOME SCENARIOS OF CLIMATE CHANGE AND THE GLOBAL ENVIRONMENT

IMAGE 2.0 has been used to compute a range of comprehensive scenarios about climate change and the global environment (Alcamo *et al.*, 1994b). Above we have described results from the baseline Conventional Wisdom scenario. Here we briefly describe results from two other types of scenarios.

Biofuel Crops and No Biofuels Scenarios.
The Biofuel Crops scenario assumes that the usage of biofuels increases from its present low levels to 74 EJ/yr in year 2050, and 208 EJ/yr in 2100. It is further assumed that 40% of total biofuel demand will be delivered by energy crops, with the remainder coming from crop residues and other sources. The No Biofuels scenario is used as a benchmark to study the sensitivity of the global system to biofuel use.

These scenarios confirm that biofuel use can be a successful strategy for lowering CO_2 emissions. However, they also show that emissions of other important compounds, such as carbon monoxide (CO), could increase. Hence it is important to examine the impact of biofuels on the full range of greenhouse gases, rather than only CO_2. Another finding of the scenarios is that land needed for energy crops could compete with land needed for food crops in Africa and Asia. Moreover, the conversion of natural vegetation to energy cropland could markedly reduce the uptake of CO_2 by the terrestrial biosphere (Alcamo *et al.*, 1995).

Ocean Realignment
The Ocean Realignment scenario investigates the possible global effects of a surprising change in natural driving forces, namely, the slowing down of ocean circulation. This scenario aims to look at the possible consequences of a low probability occurence. The assumed changes in ocean circulation lead to a slowing of the northward transport of heat in the Atlantic, and a temporary cooling of ocean and air temperature in the Northern Hemisphere. Eventually surface temperatures in the North increase because of the build-up of greenhouse gases, but the increase between 1990 and 2100 is much lower (1.5^{0}C) than in the baseline scenario (3 to 5 ^{0}C). This smaller increase in temperature reduces carbon uptake in the northern biosphere, as compared to the baseline. Consequently, under this scenario, the CO_2 level in the atmosphere is 90 ppm higher in the year 2100 than in the baseline. Results of the scenario illustrate that an unexpected, low probability event can both enhance the build-up of greenhouse gases, and at

the same time cause a temporary cooling of surface air temperatures in the Northern Hemisphere.

6. CONCLUSIONS

In summing up, the main innovation of the IMAGE 2.0 model is its presentation of a geographically-detailed, global, and dynamic view of the linked society-biosphere-climate system. With respect to society, the model represents in some detail the relation between economic and demographic trends and the generation of greenhouse gas emissions. Regarding the biosphere, it is a first attempt to simulate in geographic detail the transformation of land cover as it is affected by climatic, demographic, and economic factors. And with respect to the climate system, it dynamically couples emissions from society and the biosphere with processes in the atmosphere and ocean.

Because of its components and spatial resolution, the model is particularly well-suited to investigate both scientific and policy oriented questions. In particular, it has the potential to provide new insight into the linkages and feedbacks of the global-biosphere-climate system.

7. ACKNOWLEDGEMENTS

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Endnote

*The baseline scenario is based on the Conventional Wisdom scenario documented in: Alcamo, J., van den Born, G.J., Bouwman, A.F., de Haan, B., Klein Goldewijk, K., Klepper, O., Leemans, R., Olivier, J.A., de Vries, B., van der Woerd, H. and van den Wijngaard, R., 1994b. Modeling the global society-biosphere-climate system, Part 2: computed scenarios. *Water, Air and Soil Pollution*, 76: 37-78. This scenario takes population and economic growth assumptions from the intermediate emissions scenario (IS92a) of the IPCC (1992). The population assumptions correspond to median estimates of the U.N. Further assumptions of the Conventional Wisdom scenario are given in Alcamo, *et al.*, Ibid.

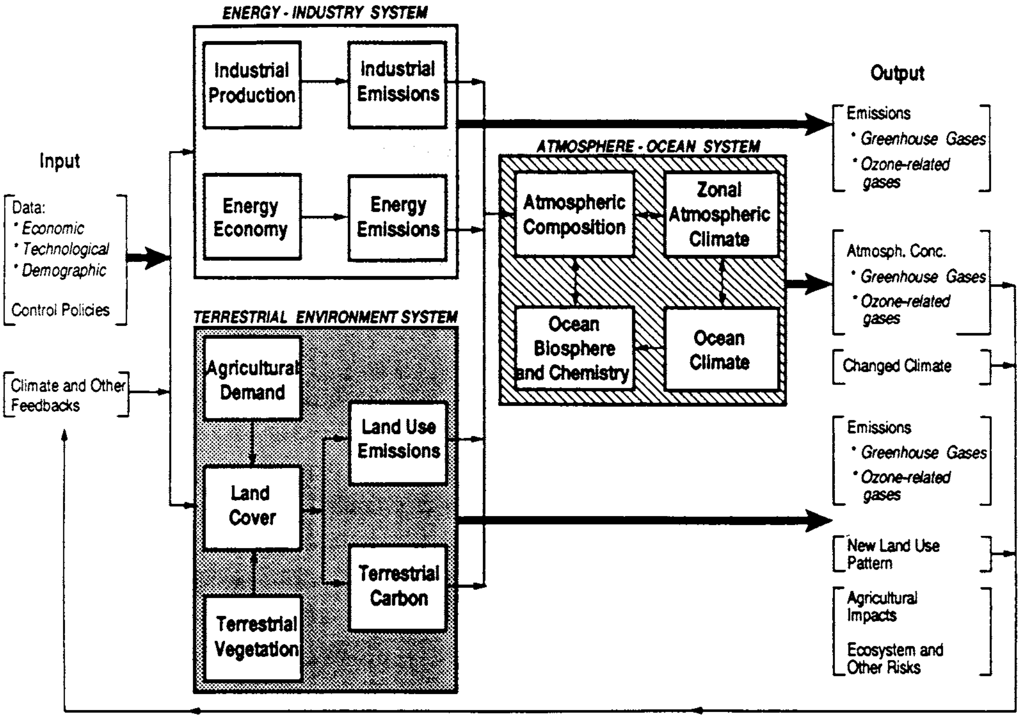

Figure 1. Box diagram of IMAGE 2.0 model. Each box represents a submodel of IMAGE 2.0.