Modelling

MODELING LAND USE/COVER CHANGE IN EUROPE AND NORTHERN ASIA

Gerhard K. Heilig
IIASA Population Project / IIASA LUCC Project

1. Project Summary

A multinational, multidisciplinary research programme is proposed with the objective of analyzing and understanding the spatial characteristics, temporal dynamics and environmental consequences of potential land-use and land-cover changes that occur and have occurred in Europe and Northern Asia over the period 1900 to 1990 from a range of socioeconomic and biophysical driving forces. The understanding. and analysis will then be used to define plausible future changes in land use and cover for the period 1990 to 2050 using different sets of comprehensive assumptions for future demographic, political, economic and social development. Europe and Northern Asia is selected because of its diversity in social, economic and political organization, which has undergone rapid changes during its recent history, with major implications for current and future land use and cover.

The research programme will be closely associated with the "Land Use/Cover Change" core project of IGBP/HDP, the "Global Change and Terrestrial Ecosystems' core project of IGBP, with research work in progress funded by the Environment Programme of EC DGXII and with national research programmes throughout the region. It should be emphasized, however, that the project will be important in its own right, by developing and testing new research methods and contributing new knowledge on land use and land cover change.

The project will involve five major phases:

1 PROJECT MANAGEMENT AND METHODOLOGY (~9 months): to strengthen the project infrastructure, organize a workshop on land-use and land cover change to review past and ongoing efforts, and to ,develop the project methodology and common case study protocol.
2 DEVELOPMENT OF AN INTEGRATED LAND-USE/COVER MODEL (~18 months): to assemble databases and develop model components (i.e., formulation and algorithms) required for continental-scale studies.
3 LUCC CASE STUDIES (~24 months): to conduct a number of case studies in prototypical ecological and socio-economic settings; apply common project protocol to establish databases, identify land-use/cover change driving forces, and project future land use and cover.
4 INTEGRATION AND POLICY ORIENTATION (~9 months): to integrate results and parameterizations obtained from case studies into a continental-scale assessment; to develop trajectories of land-use/cover changes according to consistent scenarios and a policy framework; to relate the continental-scale results of Europe and Northern Asia to global development.
5 ASSESSMENT OF POLICY IMPLICATIONS (~6 months): to formulate policy implications derived from case studies and the continental-scale assessments; to document the methodology, databases and simulation results; organize a workshop to present the methodology, results and policy implications.

Of these, four phases (i.e., phases 1, 2, 4, and 5) will primarily be the responsibility of the project core team at IIASA. The case studies foreseen in Phase 3 will to a large extent be organized and implemented by local study teams. The IIASA core team will define the common case study protocol and guide the analysis.

The project will produce results relevant to the research community, to policy-makers, and to international organizations. The project will contribute to advancing scientific knowledge, to

improving our understanding of future land use directions, and to inform policy-makers and the public about relevant land-use/cover change issues. The expected outputs can be broadly grouped as scientific results, publications, and policy applications:

1 *SCIENTIFIC RESULTS*:

- An advanced methodology for analyses of biophysical and human dimensions of land-use/cover change at different spatial and temporal scales;
- A validated model of land-use/cover change, based on improved knowledge of interrelations and mechanisms of human impacts on global environment change;
- A better understanding of the sensitivity of future land-use and land cover to different factors, e.g., technology, demographic and economic development, land-use policy, and changing environmental conditions.

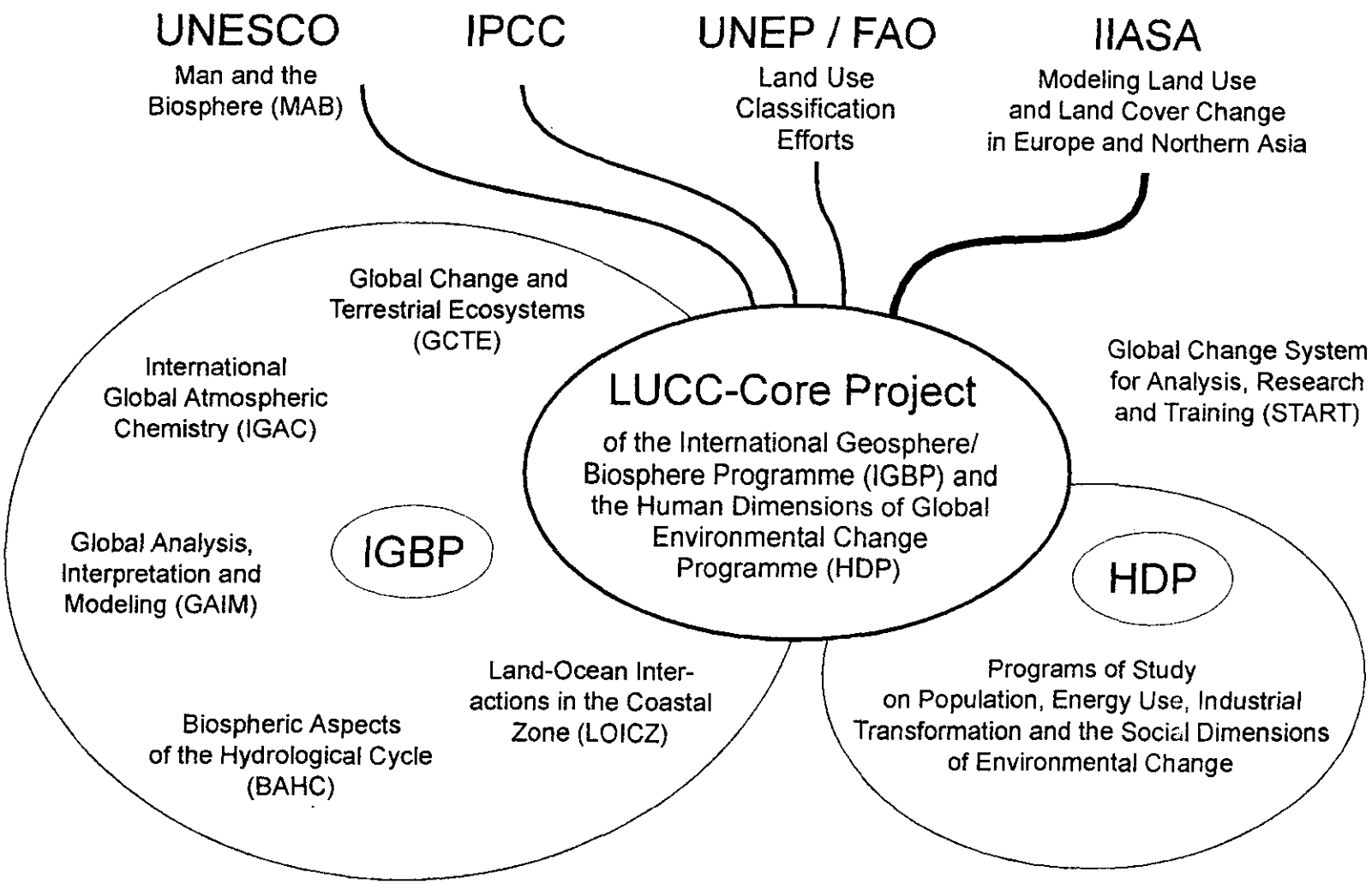
2 PUBLICATIONS:

- The main results of the project will be published in a book and in scientific papers;
- Articles on the research topic will be placed in scientific journals;
- Proceedings of workshops will be provided;
- Improved digital databases of land-use/cover types in the study region will be published;

3 APPLICATIONS:

- Projections of land-use/cover changes under selected economic, policy and climate change scenarios.
- Recommendations to policy-makers at local and national levels on political issues of land-use/cover change.
- Recommendations to national level decision-makers regarding socio-economic strategies, based on systematic projections of future land use.

Embedding of IIASA's Project on "Modeling Land-use and Land Cover Change in Europe and Northern Asia" into International Research Efforts:



Main Project Phases of IIASA's LUCC Project[1]

Phase 1: Project Management and Methodology
Activity 1 1: Project Promotion Committee
Activity 1 2: History Lessons for Land-use/Cover Modeling
Activity 13: Methodological Considerations
Activity 14: Computer Aspects
Activity 1 5: Policy Context and Scenario Framework

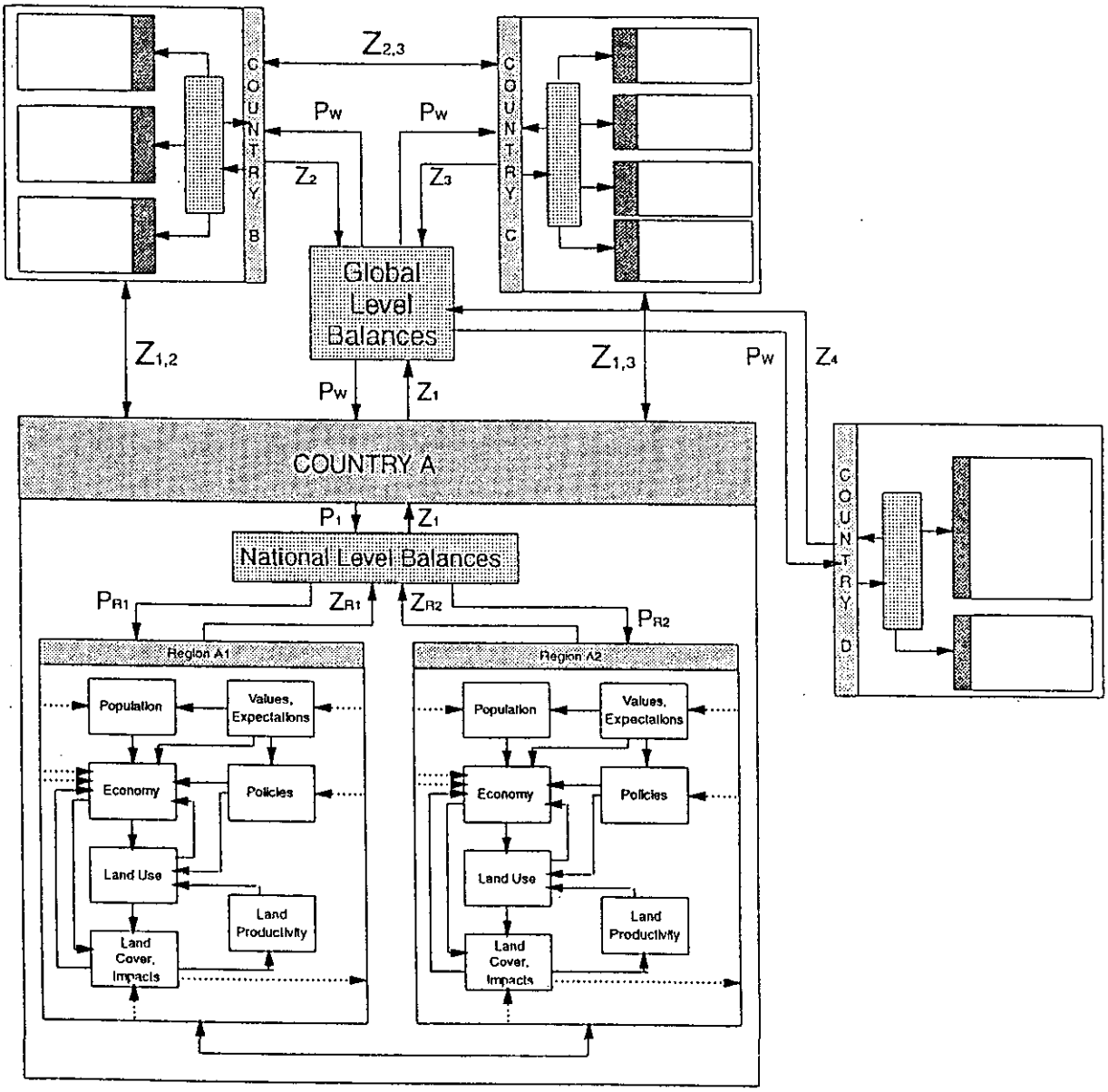
Phase 2: Development of an Integrated Land-use/Cover Model
Activity 2 1: Objectives of Integrated Land-use/Cover Model
Activity 2 2: Database Requirements and Structure
Activity 2.3: Regionalization and Typology
Activity 2 4: Aspects of Model Development
Activity 2 5: Model Validation
Activity 2 6: Model Sensitivity Analysis
Activity 2.7: Scenario Specification

Phase 3: Case Studies (by local study teams)
Activity 3 1: Case Study Methodology
Activity 3 2: Case Study Data Collection
Activity 3 3: Historical Land-use/Cover Changes
Activity 3 4: Identification of Driving Forces
Activity 3 . 5: Model Development and Validation
Activity 3 6: Long-term Projection of LUCC by Type

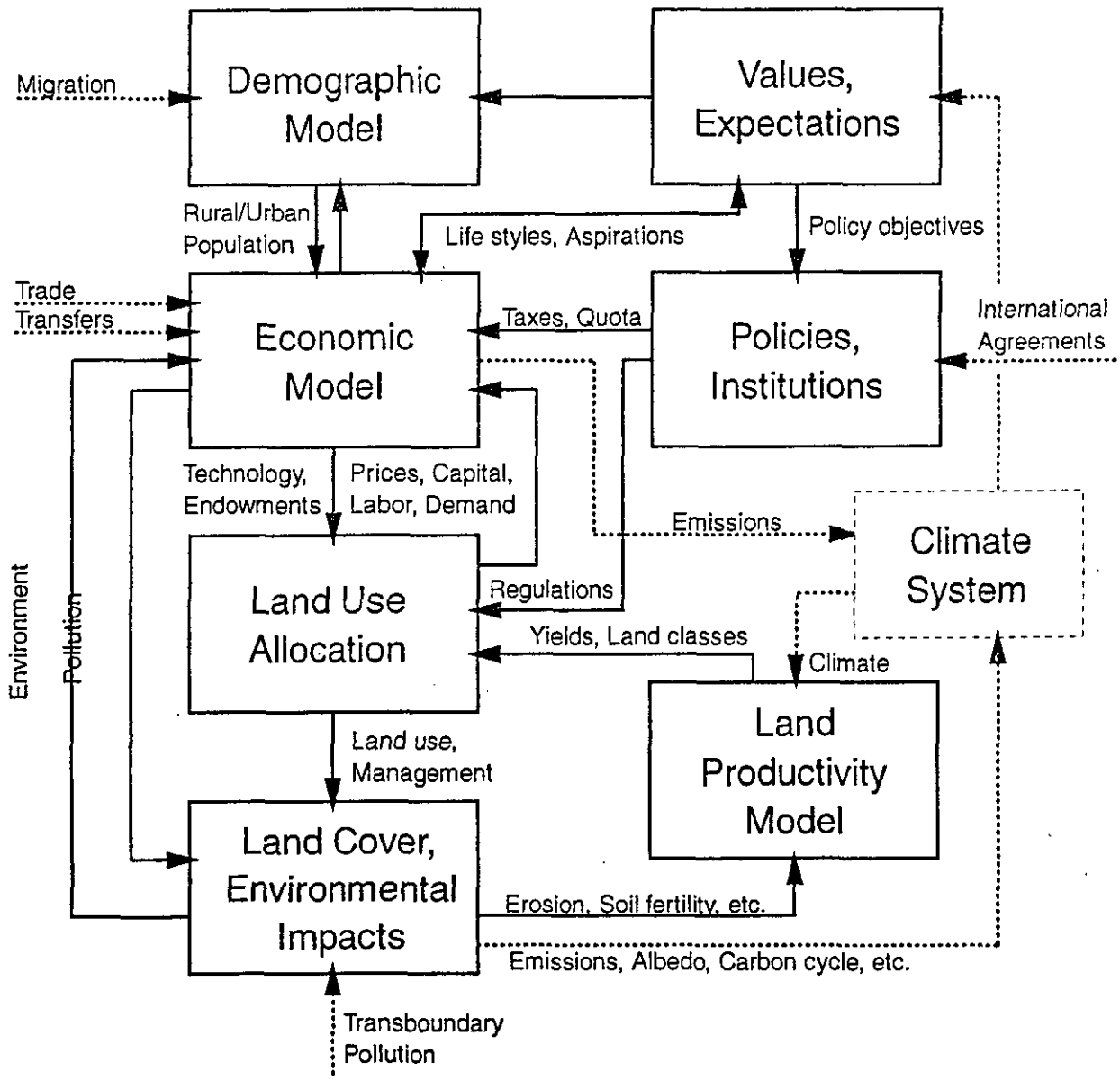
Phase 4: Integration and Policy Orientation
Activity 4 1: Integrating Results from Case Studies into Continental Framework
Activity 4 2: Long-term LUCC Projections (1990-2050)
Activity 4 3: Relation of European and Asian LUCC to Global Change

Phase 5: Assessment of Policy Implications

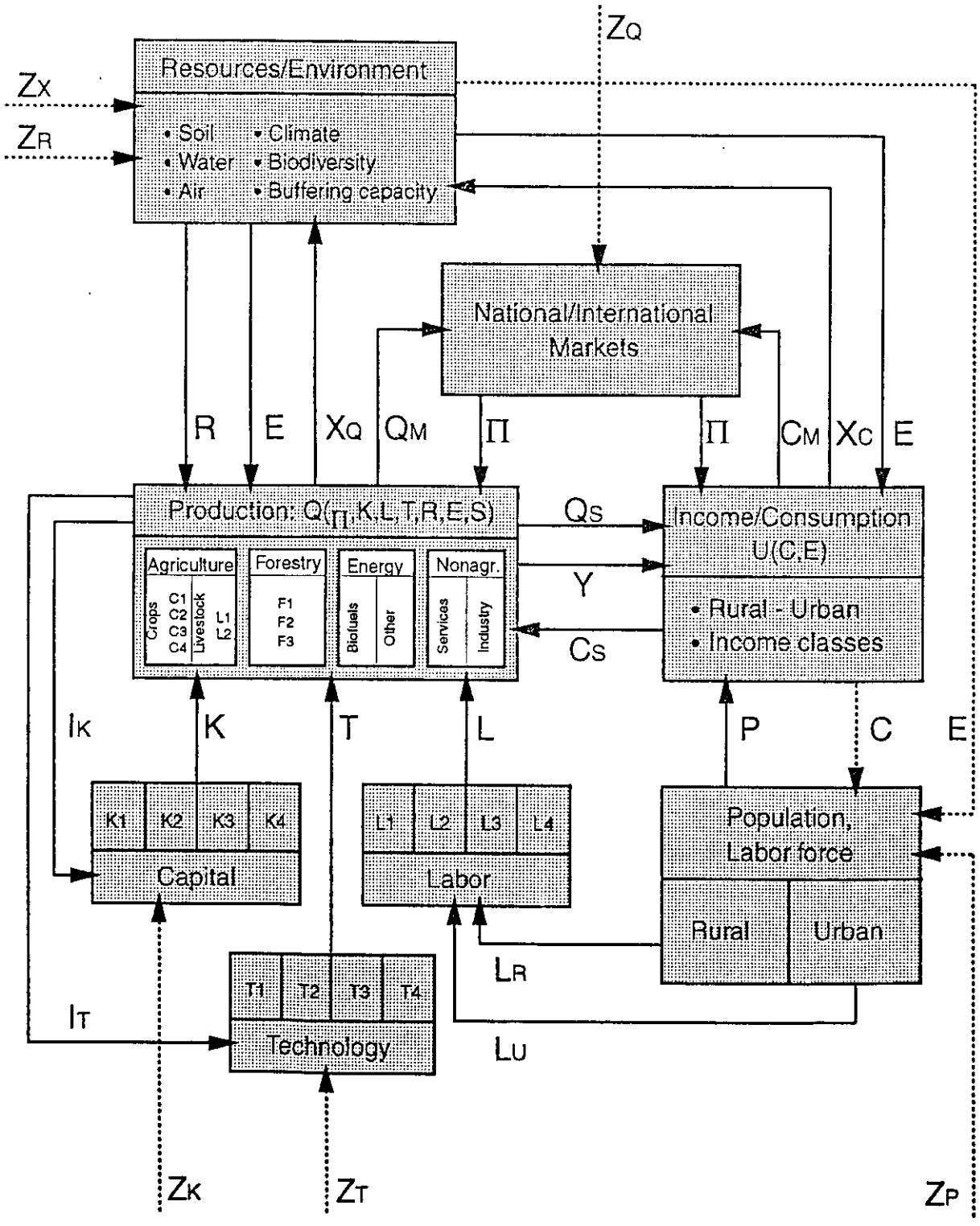
1 Phases 1, 2, 4 and 5 will primarily be the responsibility of the project core team at IIASA. Phase 3 (Case Studies) will to a large extent be organized and implemented by local study teams.


COUNTRY B
COUNTRY C
COUNTRY D
Z2,3
Pw
Pw
Z2
Z3
Global Level Balances
Z1,2
Z1,3
Pw
Z4
Pw
Z1
COUNTRY A
P1
Z1
National Level Balances
PR1
ZR1
ZR2
PR2
Region A1
Region A2
Population
Values, Expectations
Economy
Policies
Land Use
Land Productivity
Land Cover, Impacts

INTEGRATED LAND USE / LAND COVER MODELING



ECONOMIC MODEL



Production and Consumption

Q	production
Q_M	marketed production
Q_S	subsistence production
C	consumption
C_M	market consumption
C_S	subsistence consumption
C_Q	intermediate consumption
P	prices

Transboundary Flows:

Z_X	transboundary flows of pollution
Z_R	inter-regional resource flows
Z_Q	commodity trade
Z_K	capital flows
Z_T	technology transfer
Z_P	transboundary migration

Population and Labor Force

P	population
P_R	rural population
P_U	urban population
M	rural-urban migration
L	labor force
L_R	rural labor
L_U	urban labor

Stocks and Flows

K	capital stock
T	technology level
I_K	capital investment
I_T	technology investment
I_X	clean-up investment
E	environment
R	resource flow
X	pollution

INCORPORATING LAND-USE CHANGE IN EARTH SYSTEMS MODELS. THE LAND USE COMPONENT OF IMAGE 2 AND SOME CONSEQUENCES FOR ENVIRONMENTAL CONSERVATION.

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Land use, land cover and changes therein are important contributors to greenhouse gas emissions through, for example, deforestation, nitrogen fertilization and rice cultivation, but they also have a significant potential for reduction of emissions of greenhouse gases (GHGs) and thus mitigating negative impacts. The mitigation options include carbon sequestration through different forest management, forestation and advanced agricultural practices. Land use is therefore important to be taken into account for models that aim to predict future levels of atmospheric GHGs.

I will present the IMAGE 2 model which is designed to simulated global greenhouse gas emissions and atmospheric concentrations for the period 1970-2100. The model is primarily aimed to develop and evaluate policies, but for reliability and robustness of such integrated model, it should be based on state-of-the-art scientific understanding of the Earth systems (including the anthroposphere). The model therefore consists of 3 major subsystems: the Energy/Industry emissions models, the terrestrial biosphere models and the atmosphere/ocean models. IMAGE 2 simulates the emissions of GHGs from the different sectors and includes feedbacks such as the influence of climatic change and changing atmospheric CO_2 concentrations on plant and crop growth, and their distributions, as well on energy-use. External input to the different models consists of demographical, technological and socio-economical development.

This presentation will emphasize on the diversity of processes simulated in the terrestrial environment systems. The definition for the regional demands for agricultural commodities and the linkage with potential agricultural productivity will be highlighted. This part of the model leads to a dynamic simulation of land cover patterns through time and their influence on the global C cycle and emissions of GHGs, other then CO_2. The capabilities of determining the effect of different scenarios will be illustrated with the Conventional Wisdom scenario, with no policy measures to reduce GHGs emissions, and an increased forestation scenario or a biofuels scenario. Scenarios depend on the middle UN populations and economical development figures. The consequences of these scenarios for biodiversity will be highlighted. These simulations show the buildup of CO_2 in the atmosphere during the coming decades and stress the importance of the terrestrial biosphere and land use for the determination of future GHGs concentrations and further highlight the capacities to evaluate different GHGs policy measures.

ASIAN-PACIFIC INTEGRATED MODEL (AIM)

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1. Introduction

It is predicted that global warming will have a significant impact on the society and economy of the Asia-Pacific region, and that adoption of measures to cope with global warming will force the region to bear a very large economic burden. The rationale for developing the Asian-Pacific Integrated Model (hereafter, AIM) is to assess policy options for reducing greenhouse gas emissions and the impact of climate change. AIM is an integrated model composed of three linked sub-models, i.e., an emission model (AIM/emission), a climate model (AIM/climate), and an impact model (AIM/impact). It has the ability to prepare regional overviews with a focus on policy assessment in the Asian-Pacific region. This paper introduces the framework, outcomes, and future enhancement of the AIM modeling project.

2. Framework of AIM (Morita, et al., 1994)

AIM integrates emission, climate, and impact models and their component processes, as well as preparing both national and integrated global models. As shown in Figure 1, the three linked models are AIM/impact, AIM/emission, and AIM/impact.

The emission model combines an end-use energy model and a technology selection model. More than 100 technologies are evaluated for their potential to improve energy efficiency, and energy demand estimates are linked to a top-down economic model. One component of the emission model is a forest resources alternation model to estimate global greenhouse gas emissions from land use change.

The climate model was created by developing original linkages to interconnect the GCM, a regional climate change model, and the AMAC (Assessment Model for Atmospheric Composition) to determine atmospheric composition. The impact model linkage is composed of a spatial water balance model, an ecological matching model and a malaria distribution model.

3. Outcomes of AIM models in the first phase (Morita, et al., 1994)

This model development started in 1991 as one project of the Global Environmental Research Program supported by the Environmental Agency of Japan. The major outcomes from the first 3-year project are as follows:

a. A preliminary global module of AIM has been completed;
b. A prototype model of the country-wide emission models has been developed and applied to Japan, China and Indonesia;
c. Integration and application of the country-wide and global models, plus preparation and analysis of emission reduction policies and future global change scenarios;
d. Three kinds of impact models have been developed - a spatial water balance model, an ecological matching model, and a malaria distribution model;
e. The impact models were used to estimate the increased risk of droughts, floods, vegetation changes and malaria.

4. Land use/cover model in AIM

Land use /cover change is considered to be a fundamental process in AIM emission and impact models. Although the first phase of model development focused on the energy-related demand

model, land use/cover is taken into consideration in application of the model to Indonesia. At the same time, an analysis of carbon dioxide flux from tropical deforestation was started. A research report on this issue will soon be published as a CGER report (Matsuoka, et al., 1994).

4.1 Effect of deforestation and agricultural land use on CO_2 and CH_4 emissions (Morita, et al., 1994)

The AIM/emission model was applied to Indonesia. The model uses 4 sector energy services comprised of a transport sector, an industrial sector, a residential sector, and a commercial sector. In addition to these anthropogenic CO_2 emissions, those from deforestation and agricultural land use were also taken into consideration. In a "Business as Usual" scenario, the improvement in energy efficiency was simply assumed to be linear, at the rate of about 1%-per-year. Other major assumptions were: a population of 340 million by 2100; a GNP increase of 4.1-%-per-year up to 2025, followed by 3.3%-per-annum; an urbanization rate of 73%; and a deforestation rate of 2.2 million ha-per-year. Figure 2 shows the predicted emissions of CO_2 over the next 100 years. CO_2 emissions from deforestation increase early into the next century, and then decline as the remaining forests disappear. Emissions from other sources increase steadily. The main contributors of CH_4 emissions will be rice cultivation and leaks from pipelines.

4.2 Estimation of CO_2 flux from tropical deforestation

CO_2 flux released from conversion of tropical forests to other forms of land use is one of the important factors which should be taken into consideration when analyzing CO_2 mass balance in a comprehensive manner. As part of the AIM project, an estimation of CO_2 flux from tropical deforestation was conducted in view of the fact that changes in natural vegetation and forests affect CO_2 circulation.

Based on the assumption that population growth is a major factor in deforestation, AIM parameters and functions of the relationship are established using recent research on tropical forests (Figure 3). With 3 scenarios for population change, the analysis estimates CO_2 flux during the 120-year period from 1980 to 2100 in three regions - Latin America, Africa, and Asia. The results indicate 61.1 billion tC, 91.6 billion tC, and 134.5 billion tC, respectively, as medium-low, medium, and medium-high estimates of CO_2 release. Figure 4 shows a regional comparison of medium scenarios of the deforestation rate.

The results from this study will be incorporated when creating land use/cover modules in AIM models.

5. Future development of AIM project

The second phase of the AIM project started in April 1994 and was developed in collaboration with various countries in the Asian-Pacific region. It is expected that the model will continue to be used to analyze the suitability and efficiency of policies to counter the impact of global warming in the region.

Reference

Matsuoka, Y, T. Morita, and H. Harasawa, 1994: Estimation of Carbon Dioxide Flux from Tropical Deforestation, CGER report, CGER-I013-'94, 35 p.

Morita, T. et al., 1994: Development of the Asian-Pacific Integrated Model (AIM) to Evaluate Policy Options for Stabilizing Global Climate, Final Report of the Global Environmental Research in Japan.

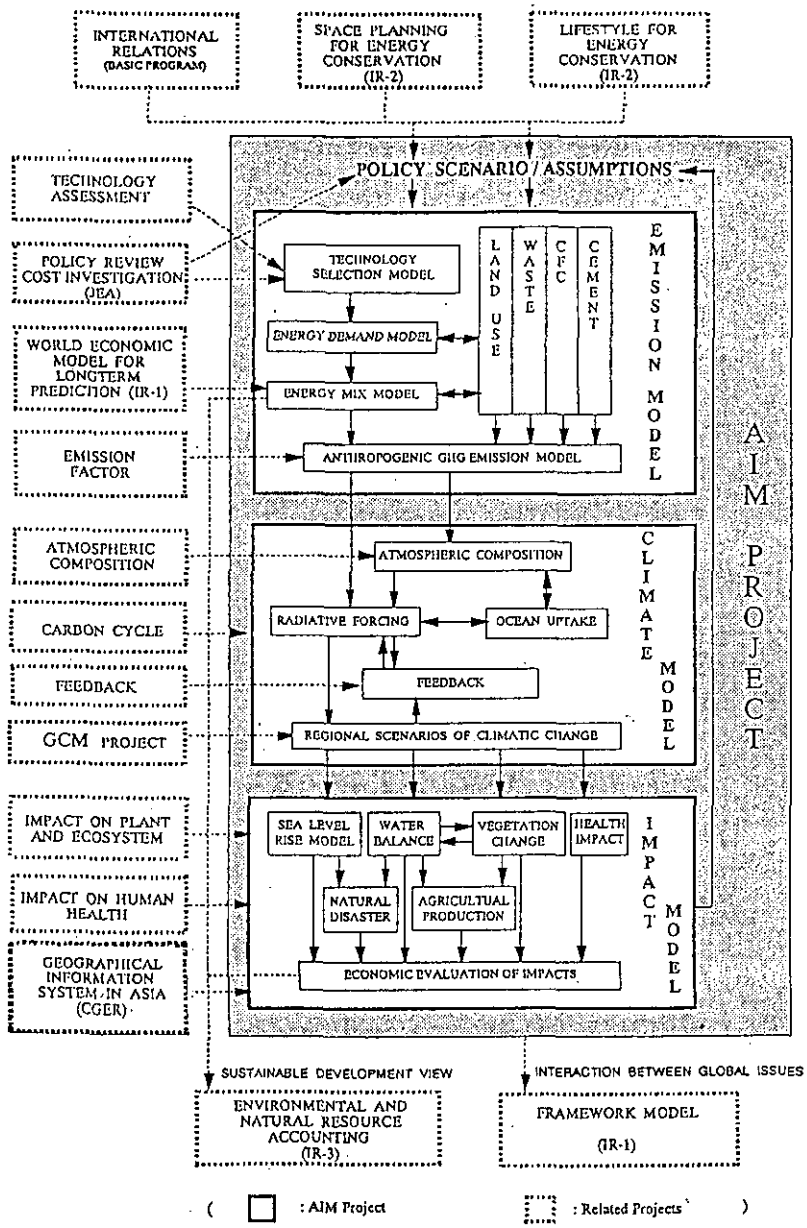

Figure 1 *Outline of AIM and related research projects in Global Environment Research Program*

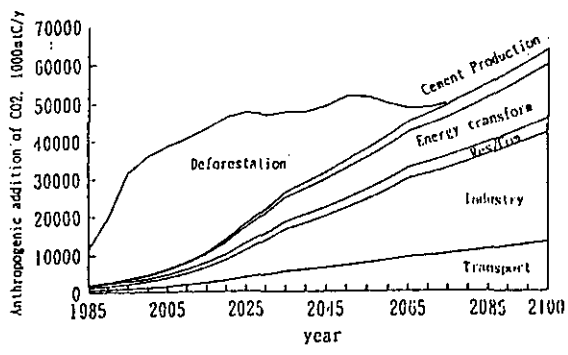

Figure 2-1 A prediction of CO_2 emissions from Indonesia (BaU case) (Morita, T. et al., 1994)

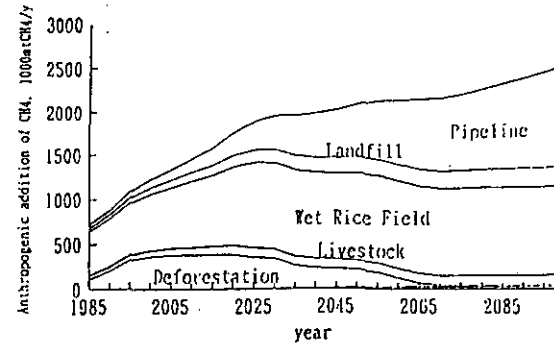

Figure 2-2 A prediction of Methane emissions from Indonesia (BaU case) (Morita, T. et al., 1994)

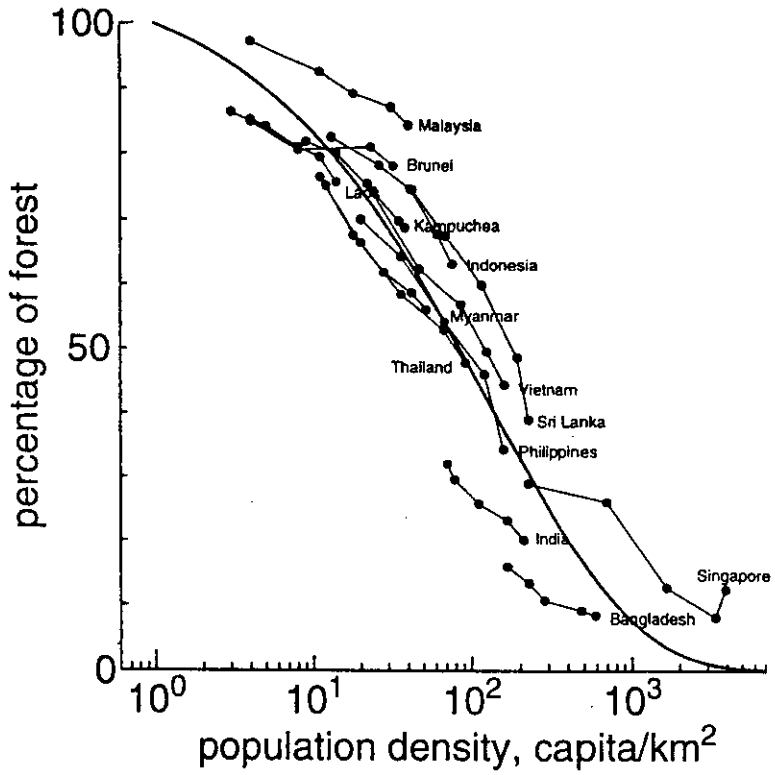

Figure 3 Regression curve for percentage of forest vs population density, Tropical Asian countries, (Matsuoka, Y. et al., 1994)

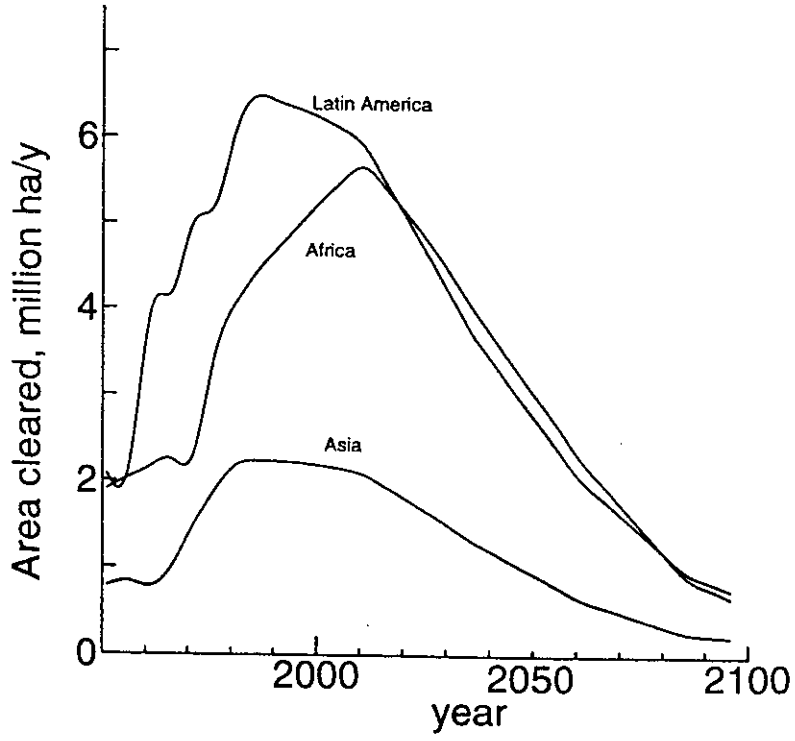

Figure 4 Regional comparison for medium scenario of deforestation rate (Matsuoka, Y. et al., 1994)