1.1 The IMAGE model

1.1.1 Introduction

To assess the consequences of population change, agricultural production levels and climate change on the desired agricultural land area, the IMAGE model was used. The Integrated Model to Assess the Global Environment (IMAGE; Alcamo et al., 1998; IMAGE Team, 2001) is a dynamic integrated assessment modelling framework for global change. The main objective of IMAGE is to support decision-making by quantifying the relative importance of major processes and interactions in the society-biosphere-climate system. The consequences of global processes on the European land-use can be indicated by the IMAGE model, after which the CLUE framework can provide more details in local land-use changes. After a short description of the IMAGE model in Section 2.1, the linkage between LEITAP and IMAGE is explained in more detail. This Chapter is concluded with Section 2.3, in which the linkage with the CLUE framework is described.

1.1.2 Background of the IMAGE model

In the IMAGE 2.2 framework the general equilibrium economy model, WorldScan, and the population model, PHOENIX, feed the basic information on economic and demographic developments for 17 world regions (see Figure 5) into three linked subsystems (see Figure 6):

- The Energy-Industry System (EIS), which calculates regional energy consumption, energy efficiency improvements, fuel substitution, supply and trade of fossil fuels and renewable energy technologies. On the basis of energy use and industrial production, EIS computes emissions of greenhouse gases (GHG), ozone precursors and acidifying compounds.
- The Terrestrial Environment System (TES), which computes land-use changes on the basis of regional consumption, production and trading of food, animal feed, fodder, grass and timber, with consideration of local climatic and terrain properties. TES computes emissions from land-use changes, natural ecosystems and agricultural production systems, and the exchange of CO2 between terrestrial ecosystems and the atmosphere.
- The Atmospheric Ocean System (AOS) calculates changes in atmospheric composition using the emissions and other factors in the EIS and TES, and by taking oceanic CO2 uptake and atmospheric chemistry into consideration. Subsequently, AOS computes changes in climatic properties by resolving the changes in radiative forcing caused by greenhouse gases, aerosols and oceanic heat transport.

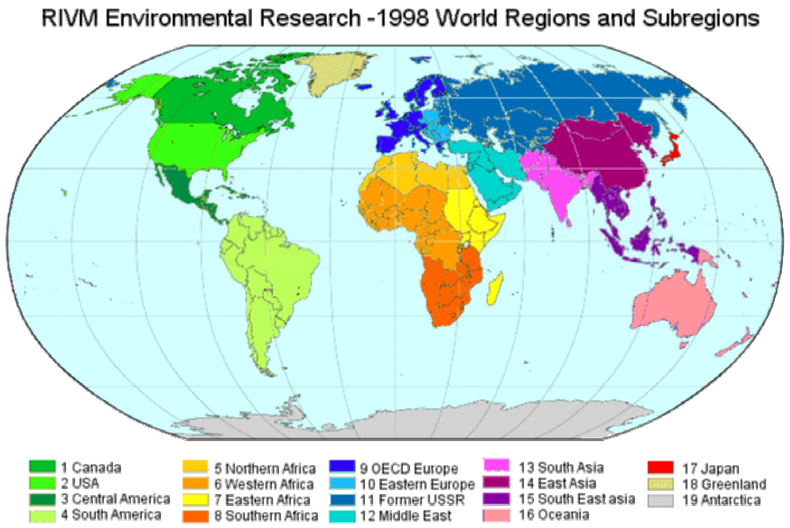

Figure 5.6: The 17 world regions plus Greenland and Antarctica in the IMAGE model

1.1.3 Link with scenarios

The four scenarios that have been used in this exercise are an elaboration of the four emission scenarios of the Intergovernmental Panel on Climate Change (IPCC), as published in its Special Report on Emission Scenarios (SRES; Nakicenovic et al., 2000) (see chapter 3). To enhance our understanding of possible outcomes of future trade policies, the rationale of these four storylines have been used to develop four different trade liberalisation scenarios. In the analyses the population numbers are taken from IPCC (Table 12; Nakicenovic et al., 2000). The global GDP numbers are taken from the report “Four Futures of Europe” (Table 12; CPB, 2003), where the same four narratives have been used as by the IPCC. However, in this CPB report more attention has been paid to the economic consequences of different trade blocks and different formations of the European Union.
The developments in the energy market, of importance for the development of the global greenhouse gas emission profiles, is taken from the latest energy study of CPB and RIVM, which used similar trends in population and economy as described above (Bollen et al., 2004). Assumptions in the agricultural sector are based on a previous study of LEITAP and IMAGE (Eickhout et al., 2004).

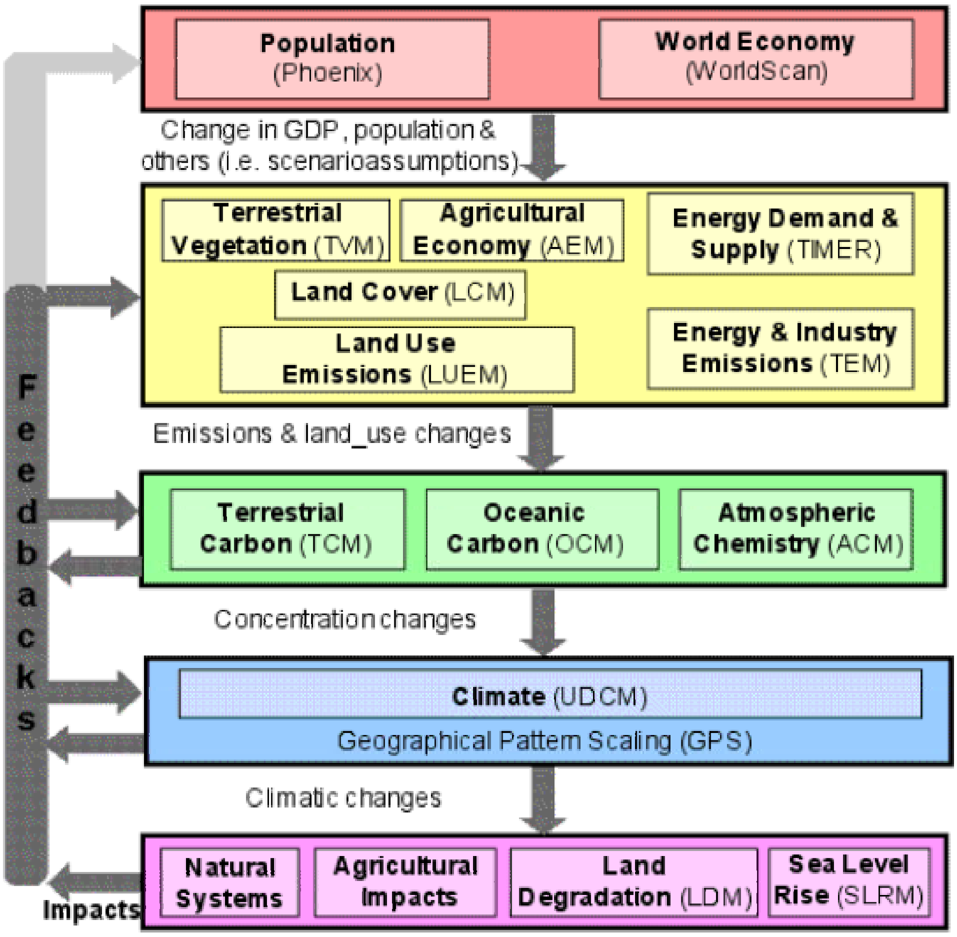

Figure 5.7: The IMAGE 2.2 framework

1.1.4 Land-use change

The IMAGE Land Cover Model simulates the spatial changes in land-cover transformation by reconciling the demands for land-use products (from LEITAP, as described in Section 1.5) with the potential of land. The potential of land is calculated by the crop growth model of IMAGE 2.2. The crop production model (Leemans and van den Born, 1994) is based on the FAO Agro-Ecological Zones Approach (FAO, 1981). This model calculates 'constraint-free rainfed crop yields' accounting for local climate and light attenuation by the canopy of the crop considered. The climate-related crop yields are adjusted for grid-specific conditions by a soil factor with values ranging from 0.1 to 1.0. This soil factor takes into account three soil quality indicators: (1) nutrient retention and availability; (2) level of salinity, alkalinity and toxicity; and, (3) rooting conditions for plants. The crop growth model is calibrated using historical productivity figures and also includes the fertilisation effect of changes in the atmospheric concentration of CO_2.

A key aspect of the Land Cover Model is that it uses a crop- and regionally-specific management factor (MF) to represent the gap between the theoretically feasible crop yields simulated by the crop production model, and the actual crop yield which is limited by less than optimal management practices, technology and know-how. If nutrients are applied optimally, there is sufficient weeding at the plantation and the harvest is optimal, the management factor reaches a value of 1. Irrigation, improvement in the harvest index and biotechnological developments can increase the management factor further to values above 1. Regional management factors are used to calibrate the model to regional estimates of crop yields and land-cover for the period 1970-1995 from FAO (FAO, 2003). For years after 1995 the management factor is a scenario variable, which is generally assumed to increase with time as an indication of the influence of technological development on crop yields. This change in crop yield is also used as input for the LEITAP analysis (see Section 1.4). Elaboration needed here!

The allocation of land-use types is done at grid cell level. Among these land-cover types are agricultural land and forest areas. Land-use transformations are in reality influenced by forces of a social, physical and economic origin. These forces are too complex to be integrated in a dynamic way in the IMAGE 2.2 model. As a proxy, the allocation of land-use types in the IMAGE 2.2 model is based on several criteria or logical rules. These are considered as simplifications of the complexity of the real forces that can be encountered due to the demand and supply of land. The Land-cover model explicitly deals with four land cover transitions:

- Natural vegetation to agricultural land (either cropland or pasture) because of the need for additional agricultural land;
- Agricultural land to other land-cover types because of the abandonment or unsuitability (under climate change) of agricultural land;
- Forests to 'regrowth forests' because of timber and fuelwood extraction;
- One type of natural vegetation to another because of climate change and/or increased water use efficiency.

The Land-cover model allocates the agricultural demand (including wood demand), grid cell by grid cell within each region, giving preference to cells with the highest crop production potential for satisfying this demand. The preference ranking of grid cells is based on 'land-use rules'. Grid cells are given a higher ranking for agricultural
production if they:

1. are close to existing agricultural land;
2. have high potential crop productivity;
3. are close to large rivers or other water bodies.

Furthermore, an extra factor is introduced that allocates a random value at grid cell level. The food or feed crops are allocated to grid cells of the type agricultural land. In each grid cell, various types of crops can be allocated, with preference to the productivity levels. The specific crops are allocated within the agricultural cell according to their crop productivity (Alcamo et al., 1998). The land-cover model results in land cover allocation of all 19 land-cover types at grid cell level. The changes in European land-use are disaggregated to a country level and are used as input for CLUE. The changes in biofuel area, calculated by the energy model and land cover model, are also used as input for CLUE.

1.1.5 Linkage between LEITAP and IMAGE

The production changes between 2000 and 2030 of LEITAP are aggregated to the IMAGE region levels, using production levels at 2000 from FAO statistics (FAOSTAT). To generate the right input for the IMAGE model the LEITAP commodities are aggregated to the IMAGE commodities (temperate and tropical cereals, rice, maize, rice, roots & tubers, oil crops, dairy and non-dairy cattle, pigs, sheep and goats and poultry).

An important aspect of land use is the need of pasture for grazing cattle. This commodity is not taken into account by LEITAP, although the land-use impact can be large. In this analysis the changes in desired production levels of meat are taken from LEITAP. Within IMAGE, the demand for animal feed is computed on the basis of the production of meat and milk. For cattle, the total feed demand is calculated on the basis of the energy requirements for maintenance, obtaining feed, growth, lactation, animal traction and calving. Feed requirements for dairy and non-dairy cattle increase along with increasing animal productivity. For the other animals the total feed requirement is calculated from feed efficiencies, i.e. the amount of feed required to produce 1 kg product.

The composition of the feed depends on the animal category considered. Grazing animals such as cattle, goats and sheep depend mainly on pasture and fodder species, while pigs and poultry rely primarily on crops. For the historical period the composition of the feed was calibrated against data from the literature for various regions.After 1995 the feed mix is scenario-driven; here, the importance of food crops in the animal diet increases at the cost of pasture and fodder species and crop residues, along with increasing intensity of production on the basis of recent trends observed (Alexandratos, 1995; de Haan et al., 1999; FAO, 1996). More details of the IMAGE grazing simulation are described in Bouwman et al. (2004). The calculated demand for grass and fodder are used as input in the Land Cover Model of IMAGE. The demand for other crop types are not used in the further analysis, since it is assumed that these quantities are considered by LEITAP. Hence, here we used the crop production levels as given by LEITAP.

Productivity changes per crop type and animal type are based on FAO assumptions in its study 'World Agriculture towards 2015/2030' (FAO, 2003). Per scenario productivity changes differ from the FAO assumptions, depending on economic growth (see Table XX, Eickhout et al., 2004).

Table 5.1: Land productivity (in kg/ha or kg/animal); relative difference with FAO prognosis for 2030

	Canada	USA	Central America	South America	North Africa	West Africa	East Africa	South Africa	Rest of Europe	Rest of CEEC	Former Soviet U.
	1	2	3	4	5	6	7	8	9	10	11
A1	5%	5%	0%	0%	0%	2,5%	2,5%	2,5%	5%	5%	5%
B1	0%	0%	0%	0%	-5%	7,5%	7,5%	7,5%	0%	5%	5%
A2	-5%	-5%	-10%	-10%	-10%	-5%	-5%	-5%	-5%	-5%	-5%
B2	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%
	Middle East	South Asia	East Asia	South-East Asia	Oceania	Japan	Rest of EU15	CEEC	Baltic countrie s	Turkey	Netherlands
	12	13	14	15	16	17	18	19	20	21	22
A1	0%	0%	0%	0%	5%	5%	5%	5%	5%	0%	5%
B1	-5%	-5%	-5%	-5%	0%	0%	0%	5%	5%	-5%	0%
A2	-10%	-10%	-10%	-10%	-5%	-5%	-5%	-5%	-5%	-10%	-5%
B2	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%

1.1.6 Linkage between IMAGE and CLUE

The changes in pasture and crop area per IMAGE region, as calculated by IMAGE, are disaggregated to a European country level (see Annex). This disaggregation is done by using the country-level production changes as computed by LEITAP. The production changes per country are calculated for crop and animal products in total. These two production changes are used to calculate the country-level change in pasture and crop area. Since we not only calculated the change in cropland and grassland on the basis of changes in production levels by LEITAP, but we also calculated the change in land on the basis of constant production levels between 2000 and 2030, we could determine a relationship between land use change and production change. It is assumed that each country within an IMAGE region encounters the same relationship of change in land as the IMAGE region itself. By using these relationships for grassland and cropland, we could disaggregate the regional land change to country-specific information.

Furthermore, climate change and regional change in biofuel area are also used as input for CLUE.