CHAPTER FOUR

Searching for the Future of Land: Scenarios from the Local to Global Scale*

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1. Introduction

Much of the scientific research concerned with land use and land cover issues is motivated by questions related to global environmental change. For example, will

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deforestation continue, and if yes, where, and at what rate? How will demographic changes affect future land use and cover? How will economic growth influence future land use and cover? What will be the magnitude of emissions of greenhouse gases related to land use and land cover? A common characteristic of these and other issues related to global environmental change is that they stimulate questions not only about past and present changes in land use and cover but also about their *future* changes. The main objective of this chapter is to summarize the state of understanding about the future of land. What are the range and predominant views of this future? What are the views on the global, continental, regional and local levels? We review what (we think) we know and don't know about the future of land by reviewing published scenarios from the global to local scale. Our aim is to identify the main messages of these scenarios especially relevant to global change issues, and to recommend how scenarios can be improved to better address the outstanding questions about global change and land use/cover.

In the first section of the chapter we describe how scenario analysis is used as a convenient tool to envision the future of land use and cover. In the next we describe the main messages of large-scale scenarios and their insights into plausible global and continental-scale trends. We then review regional and local scenarios and discuss in particular current efforts to link these scenarios with the goals of different actors influencing local land use change. Finally, we identify the shortcomings of current scenarios and how they might be improved.

2. Scenario Analysis: A Method for Anticipating the Future of Land

Although research on the future of land is clearly needed, the scientific community has been hesitant to take up this challenge – an understandable situation considering that the projection of land use/cover requires assumptions about future global vegetation (including future areas of cropland, forest and grassland) as well anticipating society's countless decisions on where to settle, where to build, where to grow its crops, and what lands to protect. Some researchers have found a partial solution to this challenge by developing *scenarios* of future land use and cover. Scenarios are plausible views of the future based on *if, then* assertions – *If* the specified conditions are met, *then* future land use and land cover will be realized in a particular way. Scenario analysis is the procedure by which scenarios are developed, compared, and evaluated. Scenario analysis does not eliminate the uncertainties about the future, but it does provide a means to represent current knowledge in the form of consistent, conditional statements about the future.

2.1 Qualitative scenarios

There are a variety of ways of classifying land scenarios. One way is to distinguish between qualitative and quantitative scenarios. Qualitative scenarios describe possible futures in the form of words rather than numbers. They can take the form of images, diagrams, phrases, or outlines, but more commonly they are made up of narrative texts, called "storylines." Qualitative scenarios have the advantage of being able to represent the views of several different stakeholders and experts at the same time. Another advantage is that well-written storylines can be an understandable and interesting way of communicating information about the future, at least as compared to dry tables of numbers or confusing graphs. A drawback is that by definition they do not satisfy a need for numerical information. For example, numerical estimates are needed of the future extent and type of forest land in order to compute the flux of carbon dioxide between the biosphere and atmosphere.

It is common now to develop qualitative scenarios through a "participatory approach" meaning a set of procedures through which experts and stakeholders work together to develop the scenarios. "Experts" are individuals with expertise relevant to the scenario exercise and "stakeholders" are individuals or organizations with a special interest in the outcomes of the scenarios. Of course, it is not always easy to distinguish between experts and stakeholders. While there exists a variety of different participatory approaches, they typically include a scenario panel made up of stakeholders and experts that develop the basic ideas of the qualitative scenarios at a series of intensive meetings. Between meetings a secretariat prepares input to the scenarios and elaborates storylines. The "SAS" (Story and Simulation) procedure is a participatory approach used to develop both qualitative and quantitative scenarios (Alcamo, 2001). Here storylines are outlined and refined at scenario panel meetings and between meetings a secretariat works with modeling teams to quantify the scenarios. A key feature of this approach is that the qualitative and quantitative scenarios are developed hand-in-hand through a series of iterations.

2.2 Quantitative scenarios

Quantitative scenarios are usually computed by formalized, computer models and provide numerical information in the form of tables, graphs and maps. A disadvantage is that their exactness implies that we know more about the future than we actually do. Another disadvantage is that the models used to compute quantitative scenarios embed many assumptions about the future. These models tend to represent a limited point of view about how the world works (as compared to qualitative scenarios) and therefore provide a narrow view of the future. Furthermore, because not all processes of land use change can be modeled, by definition quantitative scenarios omit these processes. An additional drawback is that the basics of modeling are difficult for the non-specialist to understand.

There are also advantages of producing quantitative scenarios based on models. Model developers point out that their assumptions about the world are clearly written down in the form of model equations, inputs and coefficients. Although these are not easily understandable to non-experts, the assumptions are at least documented and usually more transparent than the undocumented and unspoken assumptions behind qualitative scenarios. Another advantage of quantitative scenarios based on models is that these models are often published in the scientific

Box 4.1 **Main approaches to modeling future land use and cover.**

Rule based models/cellular automata models – Models usually based on cellular automata (CA) or similar techniques, operating at various spatial–temporal scales. Note that the original CAs operate in a homogenous environment and the states of cells depend only on the states of their neighbors, while CAs used in land use models operate in heterogeneous environments and can also take into account external driving forces such as changes in climate or product markets.

Empirical/statistical models – Both economists and natural scientists employ this category of models, although usually with quite distinct sets of explaining variables or drivers of land use change. These models are typically based on regression techniques using linear or logistic assumptions. The models can be either static (using regression output as final product) or dynamic (using regression output as suitability maps in dynamic allocation procedure).

Agent-based models – These models are usually based on an available agent-simulation library such as SWARM or CORMAS. They are applied to a broad range of themes (deforestation, agriculture, urban growth) and often as part of participatory scenario-building approach. These models are usually used to build local or regional scenarios in which agents represent people, households, or social/ethnical groups.

Macro-economic models – These models are built on general or partial equilibrium sets of macro-economic equations, in which land is not considered in a spatially explicit way, but is usually represented as a production factor. The heterogeneity of land is either ignored, or accounted for by different productivities or yield functions.

Land use accounting models – These models use a spread-sheet program to keep track of the assumptions of a scenario and their consequences on land use/cover. Linear relationships are sometimes used to compute future land use/cover as a function of changing driving forces.

literature and have therefore received some degree of scientific scrutiny. The types of models used for computing future land use and cover are presented in Chapter 7 and some of the main techniques used by the models are presented in Box 4.1.

Since there are convincing arguments for using either qualitative or quantitative scenarios, a popular current approach is to use a combination of both. All of the global scenarios presented later, and some of the regional scenarios, are combined qualitative and quantitative scenarios.

Box 4.2 Selected drivers specified in land use/change scenarios.

Demographic	Technological & Biophysical
Population size including migration	Crop yield
Size of urban vs rural population	Accessibility (infrastructure, travel distance)
	Climate
Economic	Soil characteristics
Average per capita income	Topography
Biofuels demand*	
Food demand	Other social factors
Food/crop prices	Food preferences
Food trade	Types of governance**
Status of land tenure/farm size**	Educational level**

*Typically used only in global/continental scenarios.

**Typically used only in regional and local scenarios.

Items without asterisk apply to both global/continental and regional/local scenarios.

3. Global and Continental Scenarios

3.1 Methodological issues

Independent of their type, all scenarios require a coherent set of assumptions for the driving forces of future land use/cover. The driving forces typically used by scenario developers include demographic changes, economic growth and technological development (see Box 4.2). The preparation of these input data is a major undertaking because a large number of internally consistent driving forces must be specified. (Where "internally consistent" is used here to mean driving forces that have consistent trends according to the knowledge of the scenario developer or the assumptions of the scenario.) An example of the large effort needed to specify driving forces for global ecosystem scenarios is given in Nelson et al. (2005). A common strategy for maintaining the internal consistency of driving forces is to first develop storylines, as mentioned above, that provide a logic for the many different assumptions about future changes in population and other drivers. This approach is used in the Environmental Outlook Report ("GEO") of UNEP (UNEP, 2004) and the Special Report on Emissions (SRES) of the Intergovernmental Panel on Climate Change (IPCC, 2000a).

While there are many different ways to model land changes only two of these have been used to develop global scenarios because of data deficiencies, scaling mismatches, or long preparation and run time. The two approaches are land use accounting models (Kemp-Benedict et al., 2002) and rule-based/cellular automata models (Alcamo et al., 1998; Eickhout et al., 2007; IMAGE-Team, 2001) (see Box 4.1 and Chapter 7).

Figures 4.1 through 4.3 show outcomes of selected global scenarios based on these modeling approaches. Included are scenarios from GEO (UNEP, 2002, 2004), SRES (IPCC, 2000a), and the Global Scenarios Group (Gallopin et al., 1997; Gallopin and Raskin, 2002; Raskin et al., 2002). We note that comparing scenarios produced with different methods and by different groups raises some methodological problems that should be kept in mind throughout this chapter. For example:

- The classification of land use/cover is not uniform.
- Different estimates of initial areal coverage for particular land cover types are used.
- Different methods (qualitative or quantitative) are used for developing scenarios.

3.2 Global scenario results

Most global scenarios show very dynamic changes in agricultural land (Figure 4.1) caused by the tradeoff between food supply and demand as moderated by international trade. Changes in demand for agricultural land are driven by changes in population, income, food preferences and commodity prices, while supply is driven

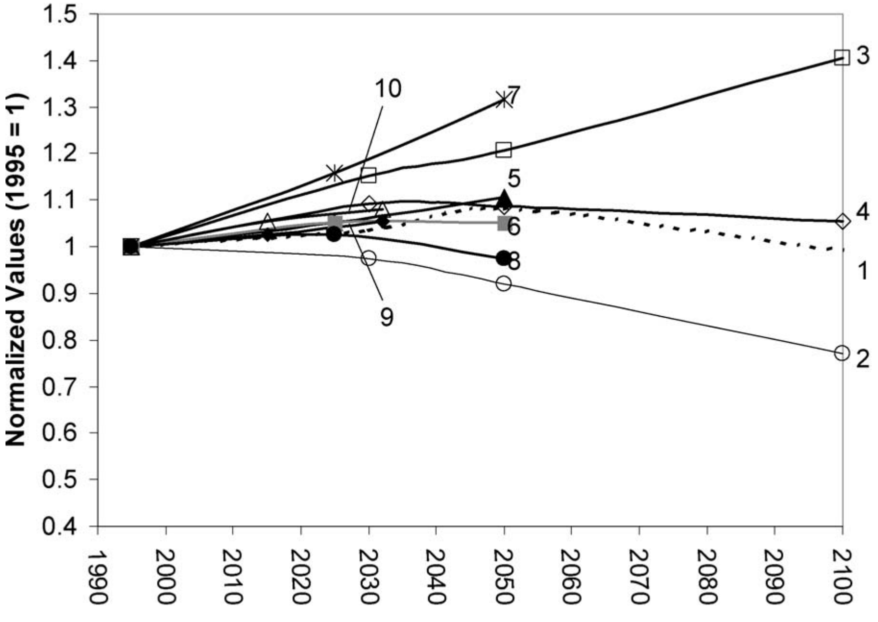


Figure 4.1 Global scenarios of agricultural land from 1995 to 2100.
Sources: Scenarios 1, 2, 3, 4: IPCC-SRES scenarios "A1," "A2," "B1," "B2" (IPCC, 2000a, 2000b) computed with IMAGE model (IMAGE-Team, 2001). Scenarios 5, 6, 7, 8: Scenarios of Global Scenario Group "Market Forces," "Policy Reform," "Fortress World," "Great Transition" computed by PoleStar model (Kemp-Benedict et al., 2002). Scenarios 9, 10: "GEO-3" scenarios (UNEP, 2004) "Markets First," "Policy First" computed with PoleStar model. "Agricultural land" comprises the land cover classes "Agricultural Land" and "Extensive Grassland" within the IPCC-SRES scenarios computed by the IMAGE model, and is the sum of "Cropland" and "Grazing Land" in the remaining scenarios.

by agricultural management, fertilizer input, soil degradation, and climate-related changes in the biophysical suitability of land for agricultural production.

Scenarios with a greater extent of agricultural land (Figure 4.1) result from assumptions about high population growth rates together with low but steady economic growth, which combine to stimulate large increases in food demand. At the same time assumed slower rates of technological progress lead to slow to negligible increases in crop yield. These combined effects lead to a sizeable expansion (up to 40%) of agricultural land between 1995 and 2100 (Figure 4.1). The majority of scenarios show a growth in agricultural land during this period. The scenarios with a smaller extent of agricultural land have lower population assumptions leading to smaller food demands while higher economic growth stimulates technological progress leading to rapid increases in crop yields. The sum of these effects is lower demand for agricultural land, with the lowest scenario showing a decline of more than 20% in the global area of agricultural land. Such large changes could have an important effect on the magnitude of greenhouse gas emissions, release of nutrients and other trace substances to aquatic ecosystems, and other large-scale impacts on the earth system.

One of the key uncertainties in these scenarios is the question of how the world's population will be fed in the future – Will food come from the *intensification* of agricultural land, that is, by boosting crop yields with increasing fertilizer, irrigation and other inputs, or from *extensification*, by expanding the hectares of cultivated land? How much food will be provided by imports, and conversely, how much agricultural production will be exported? The scenarios presented in Figure 4.2 assumed various degrees of extensification, intensification and world food trade and their wide range reflects the uncertainties of these factors.

The global forest scenarios largely mirror the agricultural scenarios (Figure 4.2), and illustrate both the positive and negative aspects of existing scenarios. On the one hand, the forest scenarios are a valuable illustration of the connection between agricultural trends and the future tempo of global deforestation or afforestation. On the other hand, these scenarios imply that forest trends are driven almost exclusively by cropland expansion or contraction. They deal only superficially with driving forces such as global trade in forest products and the establishment of future forest plantations to sequester carbon from the atmosphere. Global scenarios in general need to incorporate many more of the actual driving forces of land use/cover change and in a more realistic way.

There are very few published global scenarios of changes in urban area (Figure 4.3) and these give a limited view of urban developments. All show a steep increase over the next decade, with about half estimating a stabilization of urban areas by 2025. Stabilisation, however, occurs only after urban areas are about 50% larger than their 1995 area. The remaining few scenarios show urban areas still expanding at a linear or exponential rate in 2050. The set of scenarios in 2050 shows an increase from 1.5 to 2.5 over the extent of urban land in 1995. These estimates are based on the multiplication of estimates of current urban space requirements per person (for different world regions) times the future trend in urban population (Kemp-Benedict et al., 2002). Hence they do not account for changing spatial requirements of settlement areas.

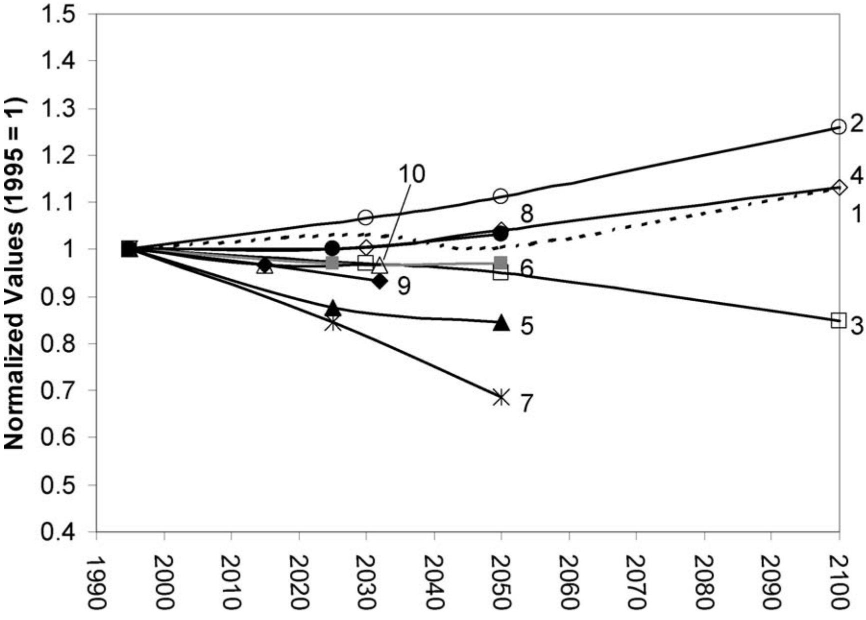


Figure 4.2 Global scenarios of forest land from 1995 to 2100. The key to scenario numbers is the same as in Figure 4.1. "Forest land" is defined as the sum of "Carbon Plantations," "Regrowth Forest," "Boreal Forest," "Cool Conifer Forest," "Temperate Mixed Forest," "Temperate Deciduous Forest," "Warm Mixed Forest," and "Tropical Forest" within the SRES scenarios computed by the IMAGE model. For the remaining scenarios forest land is the sum of "Natural Forest" and "Plantation."

Figure 4.4 presents the assumptions of some important drivers of the global scenarios. These are global averages of the values assumed for various world regions. The driver with largest relative increase is income and this affects the change in agricultural area particularly through increases in per capita food consumption. Income growth also influences the assumption for nitrogen fertilizer input and other variables in some scenarios. Assumptions about population growth affect the total crop production (per capita caloric uptake multiplied by population). Note that the assumed growth of population is modest compared to growth of income. The increase in total crop production (assumed or computed across all scenarios) is partly satisfied on new agricultural land and partly by augmenting production on existing land (we return to this issue later). Crop yield increases from 10 to 70% between 1995 and 2050 depending on the scenario, primarily because of an increase of 20 to 70% in the amount of nitrogen fertilizer applied per hectare, and partly because of favorable changes in climate. The global average caloric intake does not significantly increase, although most scenarios assume a marked increase in food consumption in developing parts of the world.

We note that driving forces in the global and other scenarios described in this paper are almost always assumed to be external factors that drive land use changes. In reality not only is land use change driven by external factors, but land use change in turn feeds back to these external factors. For example, migrants escaping a threat-

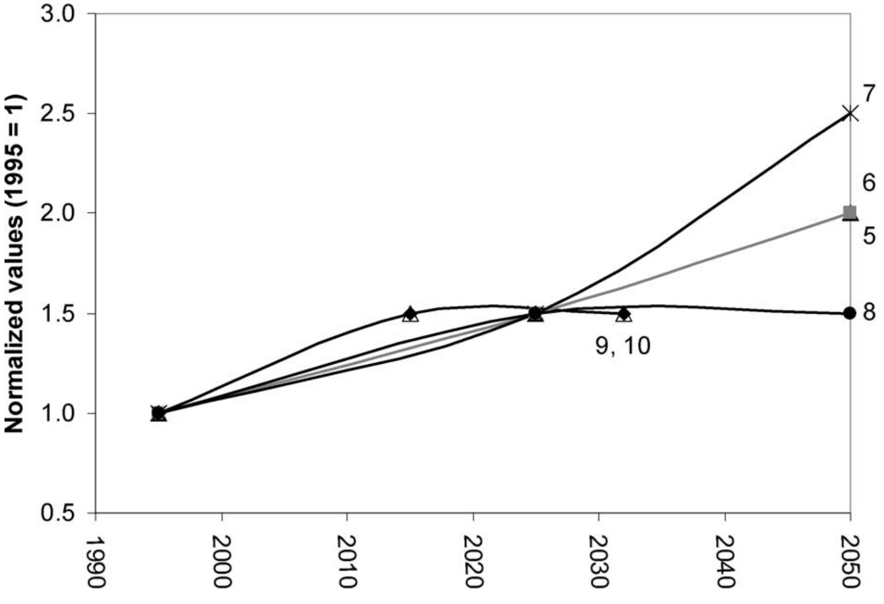


Figure 4.3 Global scenarios of urban land from 1995 to 2050.
Sources: Scenarios 5, 6, 7, 8: Scenarios of Global Scenario Group "Market Forces," "Policy Reform," "Fortress World," "Great Transition" computed by PoleStar model (Kemp-Benedict et al., 2002). Scenarios 9, 10: "GEO-3" scenarios (UNEP, 2004) "Markets First," "Policy First" computed with PoleStar model.

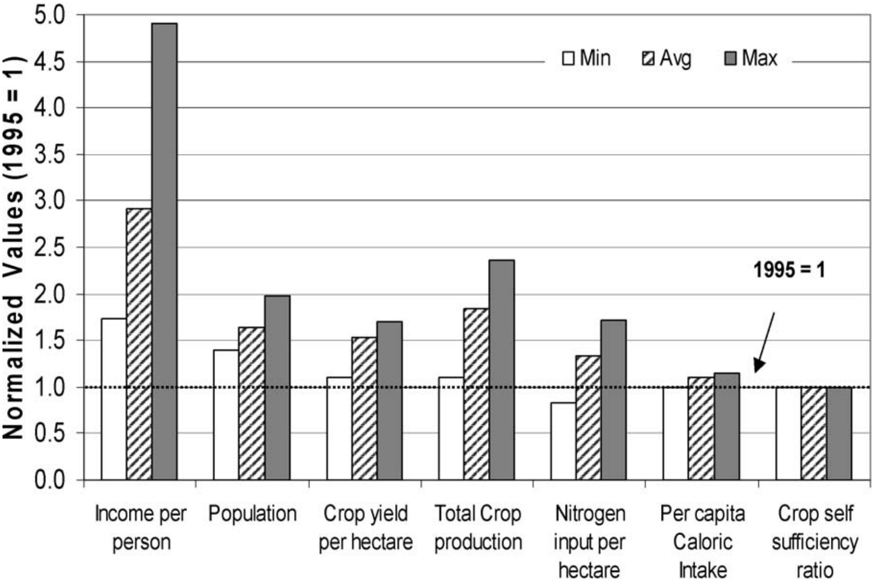


Figure 4.4 Drivers of global scenarios of land use and cover from 1995 to 2050.

ening political or economic situation outside of a region could be major drivers of changes within a particular region and could eventually cause a depletion of suitable agricultural land, which in turn could dampen the migration rate into the region. Including feedbacks to driving forces is an important task for scenario developers and is further discussed in Section 6.

3.3 African scenario results

The same tools and approaches used to develop global scenarios have been applied to continental-scale scenarios. To illustrate the differences between trends in developing and developed parts of the world we review scenarios for Africa and Europe. By comparing these regions we also show the consequences of increasing food demand (Africa) and stabilizing food demand (Europe) on future land use/cover.

The scenarios we review for Africa come from the same references as the global scenarios with the addition of the FAO "Agriculture towards 2015/2030" study (FAO, 2000) and the OECD "Environmental Outlook" study (OECD, 2001). To interpret these scenarios it is useful to examine results for different time periods. Focusing on trends from 1995 to 2025, almost all scenarios indicate a continuous expansion of agricultural land, with an intermediate estimate of 25% and a range from 0 to 45% (Figure 4.5). By comparison, the actual net expansion of agricultural land between 1980 and 1995 was only about 2%. The scenarios, however, take into account the additional agricultural land needed to satisfy both a growing population and a higher per capita food demand arising from accelerating economic growth rates. In addition, some scenarios include large areal demands for biofuel crops as a possible future strategy to reduce greenhouse gas emissions.

Between 2025 and 2050, the scenarios begin to take on more distinctive trends. The higher scenarios show an expansion of agricultural land from 1995 to 2050 of about 40 to 60%, reflecting the assumption of higher population growth (compared to other scenarios) and slower diffusion of technology which hinders Africa from benefiting from advances in agricultural technology. The lower scenarios result from assuming lower population and a vigorous exchange of information, technology, and products across borders which leads to higher economic efficiency of agricultural production and higher crop yields. Comparing 2050 to 1995, there is a net increase in agricultural land in all but a few of the scenarios.

Expanding the time horizon to 2100 (Figure 4.5) reveals clearly-defined turning points at which the trend in agricultural land changes its direction between 2010 and 2050. These turning points occur in several different scenarios and correspond to an eventual slowing of food demand and technological "catch-up" in Africa which accelerates improvements in crop yield. The net effect is a shift from expanding to contracting agricultural land. The fact that these turning points are apparent only after several decades illustrates the importance of considering the long term trend of land use/cover change.

According to most scenarios, the expansion of agricultural land causes a continuing reduction in African forested land up to 2025 (Figure 4.6) which is likely to have ongoing consequences on biodiversity, water resources, climate and other aspects of Africa's regional environment. Although the scenarios indicate a contin-

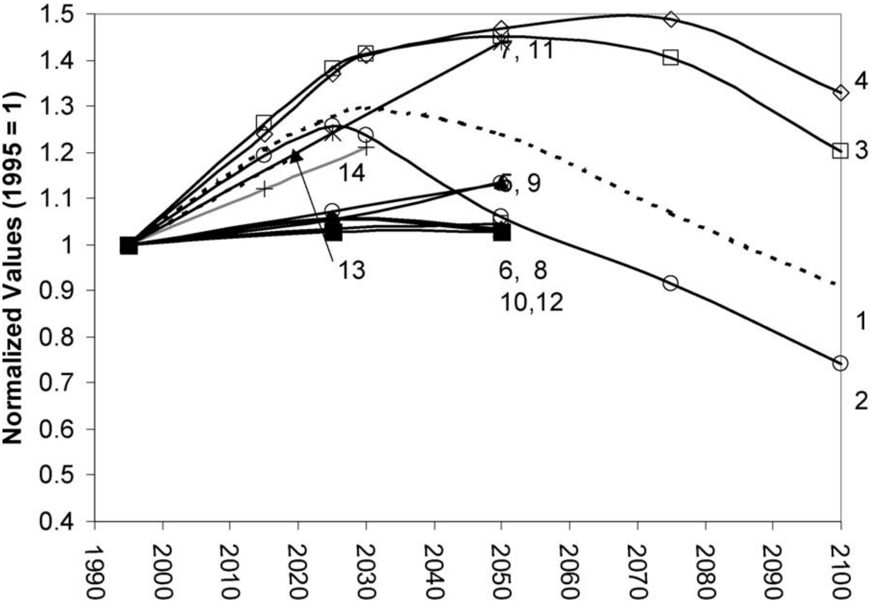


Figure 4.5 Scenarios of agricultural land in Africa from 1995 to 2100.
Sources: Scenarios 1, 2, 3, 4: IPCC-SRES scenarios "A1," "A2," "B1," "B2" (IPCC, 2000a, 2000b) computed with IMAGE model (IMAGE-Team, 2001). Scenarios 5, 6, 7, 8: Scenarios of Global Scenario Group "Market Forces," "Policy Reform," "Fortress World," "Great Transition" computed by PoleStar model (Kemp-Benedict et al., 2002). Scenarios 9, 10, 11, 12: "GEO-3" scenarios (UNEP, 2004) "Markets First," "Policy First," "Security First," and "Sustainability First" computed with PoleStar model. Scenario 13 refers to the "Reference Scenario" of the OECD "Environmental Outlook" study computed by PoleStar model (Kemp-Benedict et al., 2002). Scenario 14 addresses the "Reference Scenario" of the FAO "Agriculture towards 2015/30" study. "Agricultural land" is defined as in Figure 4.1.

uation of deforestation, they also show a slowing of the rate of deforestation. As compared to a rate of 0.8% per year from 1980 to 1995 (FAO, 1999, 2003), the scenarios show a rate of 0.2 to 0.7% per year between 1995 and 2025. However, the scenarios may in general underestimate deforestation because they do not include a comprehensive description of the many causes of changing forest land.

After 2025 the slowing and eventual reversal of agricultural expansion also results in a further slowing and reversal of deforestation (Figure 4.6). Some scenarios even show a significant *expansion* of forested area by 2100 relative to 1995. This raises interesting questions – If the pressure of expanding cropland is alleviated, can deforestation be reversed within this time frame? (See Box 4.3.) In particular, is it ecologically feasible for tropical forest ecosystems to re-establish themselves within a few decades as in these scenarios? And what are the consequences of this reversal on terrestrial biodiversity, the global water cycle and other aspects of the earth system? By stimulating such questions, scenario analysis provides a useful input to the research agenda of earth systems science.

The assumptions for the drivers of the African land scenarios are depicted in Figure 4.7. As in the global case, income grows much faster than population. Av-

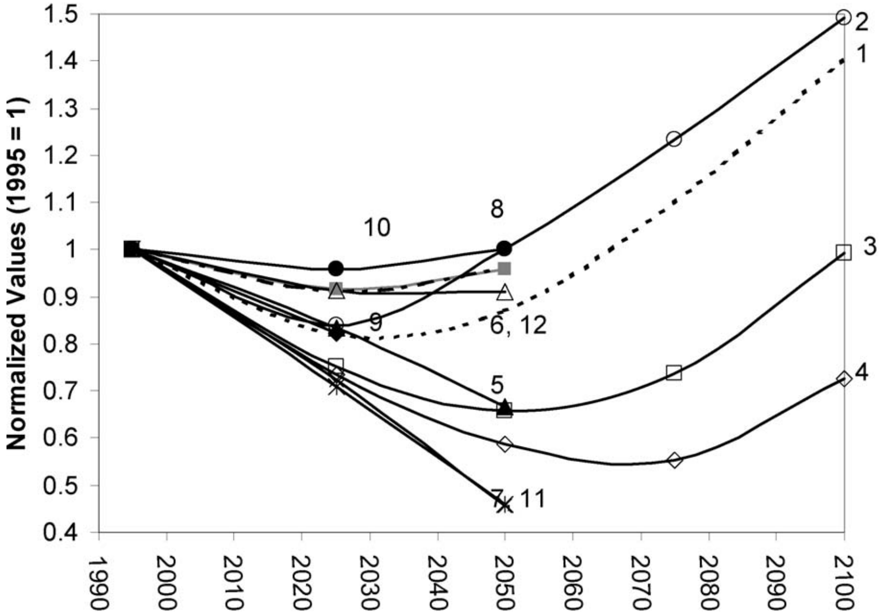


Figure 4.6 Scenarios of forest land in Africa from 1995 to 2100. The key to scenario numbers is the same as in Figure 4.5, except the scenarios 13, and 14 which do not contain forest land cover. "Forest land" is defined as in Figure 4.2.

erage income growth is about a factor of 6 between 1995 and 2050. Yet this very large growth in income does not translate into a similarly large increase in caloric intake (10 to 30% during the same period, depending on the scenario). Apparently the scenarios assume that it is the quality rather than quantity of food that is lacking in Africa. While the average scenario assumes a population increase of a factor of 2.6, total crop production increases by a factor of 3, so food production is assumed to more than keep up with the population. Only for the lowest scenarios does the increase in population exceed the increase in crop production. In these cases an increase in imported food partly compensates for the production gap.

Crop yield grows by an average factor of two, stimulated by the factor of 4 increase of nitrogen fertilizer input per hectare. Increasing yields make it possible to gain part of the new crop production on existing agricultural land. The value of the food self-sufficiency ratio (production divided by production plus consumption) is currently approximately 0.9 indicating that Africa is a net importer of food. As shown in Figure 4.7, this ratio will decrease about 10% between 1995 and 2050 across all scenarios indicating a deepening dependence of Africa on food imports.

3.4 European scenario results

The European scenarios we review here are the same as the global scenarios with the addition of the following studies: "Ground for Choices" (WRR, 1992), the OECD "Environmental Outlook" (OECD, 2001), and the EURURALIS study

Box 4.3 **Is a quick reversal of deforestation feasible?**

The African scenarios indicate that a slowing and reversal of agricultural land expansion could halt deforestation and lead to reestablishment of the tropical forest within a few decades. Is this realistic? In principle, the answer is, yes, with respect to both biomass accumulation and spatial coverage (e.g. Achard et al., 2002, 2004; IPCC, 2000b; Otsamo et al., 1997; Rudel et al., 2005; Silver et al., 2000). In terms of plant biomass and soil carbon, a forest may require longer to recover, from a few decades to a century (Silver et al., 2000). The rate of re- or afforestation at a given site depends on climatic conditions, soil fertility, and seed dispersal and in case of managed forests and plantations also management options. Silver et al. (2000) also found that on average tree biomass accumulated fastest on abandoned agricultural land as compared to other types of abandoned land. On the other hand, agricultural land is often abandoned because of soil degradation associated with decreased productivity. In this case Zanne and Chapman (2001) found that the renewal of biomass will take longer than on abandoned agricultural land with soils in good condition. Under any circumstances the restoration of tree biodiversity and forest structure may need a much longer period of time, while other types of biota (insects, herbaceous plants, fungi) may require shorter or longer periods of time to recover, or may not be able to recover at all (as in the case of large mammals requiring large undisturbed habitats).

Regarding the rate of deforestation as compared to afforestation, several of the scenarios for Africa imply that the tempo of these two processes are of the same order of magnitude. By comparison, Rudel et al. (2005) found that observed tropical deforestation is on the average twice as rapid as re- and afforestation, based on a relatively small number of studies of individual countries.

To sum up, some but not all aspects of a tropical forest may be fairly rapidly re-established after the pressures of deforestation are released.

(Klijn et al., 2005). The available set of scenarios of Europe's agricultural land give a wide range of views (Figure 4.8). The lower boundary is set by the "Ground for Choices" study (WRR, 1992) which estimated the impact of steadily decreasing agricultural subsidies up to 2015 and used an optimization approach for agricultural production and labor costs. As a result, these scenarios show 35 to 80% shrinkage in agricultural land relative to 1995. A more typical result is given by the IPCC-SRES scenarios as applied in the EURURALIS Project (Box 4.4) which indicate a decrease of around 3 to 6 percent between 1995 and 2030 in the 25 countries of the European Union.

At the opposite extreme, the highest IPCC-SRES scenario suggests that expanding the export of agricultural commodities from Europe could result in a 35% expansion of agricultural land (relative to 1995). The scenarios in-between do not show large changes up to 2025. Afterwards, however, they exhibit a wide range of

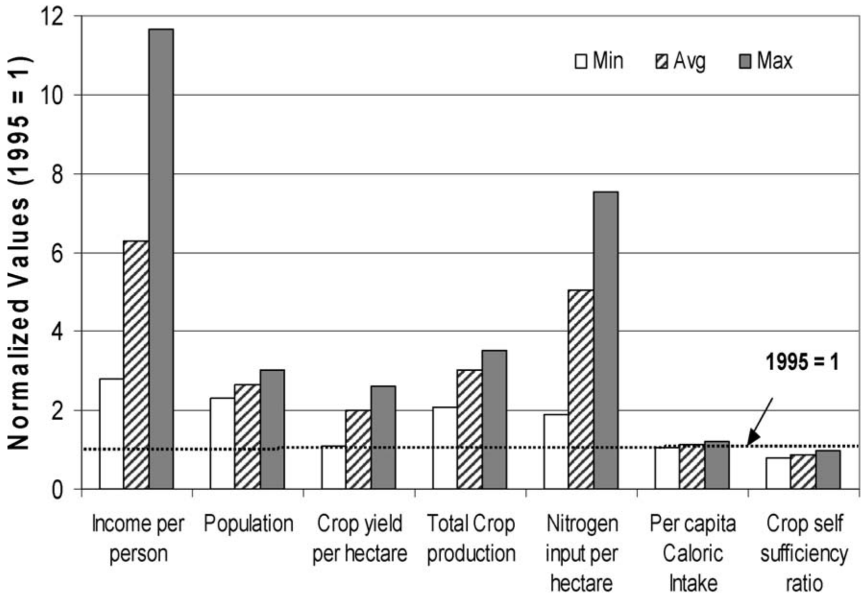


Figure 4.7 Drivers of scenarios of land use and cover in Africa from 1995 to 2050.

different trends and views about the future. The fact that most scenarios begin to diverge only after 2025 is another illustration of the importance of incorporating a longer time horizon for studies of future land use and cover. Some agricultural scenarios show a change in direction but this occurs later than in the African scenarios.

Similar to the agricultural scenarios, the forest scenarios do not show large changes up to 2025, but sharply diverge afterwards (Figure 4.9). Several long-term scenarios show a reversal in the trend of decreasing forest area at mid-century in response to declining agricultural land area. The rate of reforestation is slower here than in the African forest scenarios (Figure 4.6), and may be feasible because of the heavy management of Europe's forests.

Estimates of future forest coverage in most studies are computed in the same way as in the global and African scenarios in that changes in forest area only mirror changes in agricultural area. Most forest scenarios neglect the factors that determine the extent of forest area in Europe such as policies for nature protection and landscape preservation, forest management practices, and trade in wood products. (An exception are the EURURALIS scenarios shown in Box 4.4 which examine European land use policies in detail and computed ongoing abandonment of agricultural land and an increase in "natural land" which is likely to include new forest areas.) Another deficit is that forest scenarios of Europe and other regions usually do not distinguish between primary and secondary forests, which have dissimilar roles in the regulation of the water cycle, the support of species, and other global change processes.

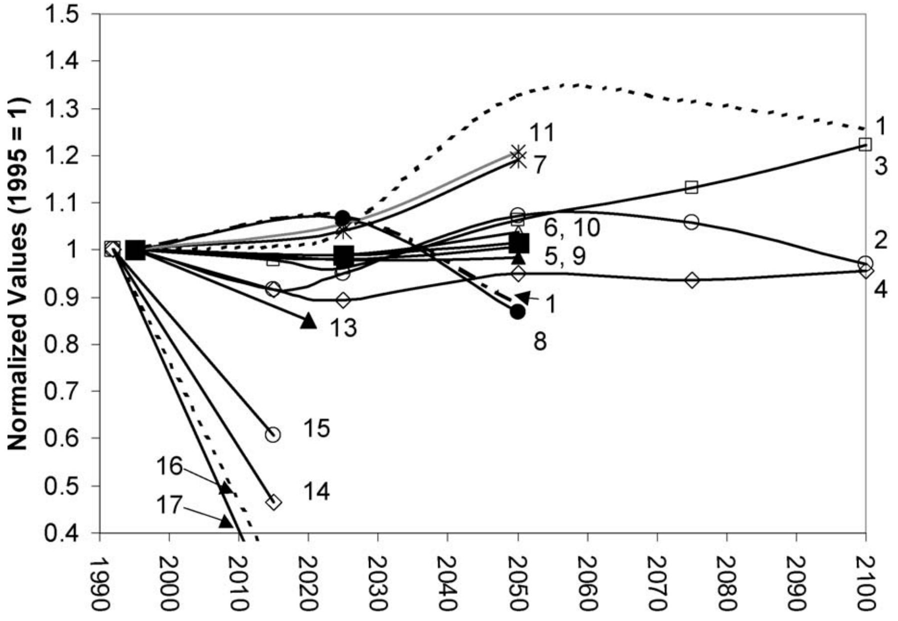


Figure 4.8 Scenarios of agricultural land in Europe from 1995 to 2100.
Sources: Scenarios 1, 2, 3, 4: IPCC-SRES scenarios "A1," "A2," "B1," "B2" (IPCC, 2000a, 2000b) computed with IMAGE model (IMAGE-Team, 2001). Scenarios 5, 6, 7, 8: Scenarios of Global Scenario Group "Market Forces," "Policy Reform," "Fortress World," "Great Transition" computed by PoleStar model (Kemp-Benedict et al., 2002). Scenarios 9, 10, 11, 12: "GEO-3" scenarios (UNEP, 2004) "Markets First," "Policy First," "Security First," and "Sustainability First" computed with PoleStar model. Scenario 13 addresses the OECD Environmental Outlook "Reference Scenario" computed by PoleStar model (Kemp-Benedict et al., 2002). Scenarios 14, 15, 16, 17: WRR scenarios "Nature and Landscape," "Regional Development," "Free Markets and Free Trade," and "Environmental Protection."

The assumed rate of change of driving forces in Europe (Figure 4.10) is more moderate than for Africa (Figure 4.7). This applies in general to developed versus developing regions in existing scenarios and reflects the thinking that Europe and other industrialized parts of the world will materially develop much less in the coming decades than Africa and other developing regions. Perhaps this is a too narrow a view of the future since it is imaginable that various social, economic or political events could narrow or widen the gap in growth between developed and developing countries.

Population growth assumptions range from a small decrease to a small increase, while income growth ranges from a factor of 1.5 to 3.3 from 1995 to 2050 (for the various scenarios). In the case of Europe (as other industrialized world regions) the increase in income does not translate into an increase in caloric intake since this is already at its saturation level. Crop yields modestly increase, because of improved agricultural management, and because of increased fertilizer input in some scenarios. The average scenario assumes that nitrogen fertilizer input remains constant, while the lowest assumes a decrease of 30% and the highest an increase of 50% between 1995 and 2050. Europe is currently a net food import area (self-sufficiency

Box 4.4 European scenarios (2000–2030) from the EURURALIS Project.

EURURALIS was sponsored by the Netherlands as part of its chairmanship of the European Union in 2004 with the aim to analyse potential land use/cover change in Europe (Klijn et al., 2005). Four scenarios were evaluated based on the IPCC SRES global storylines. A number of models were used to translate the scenarios into high resolution assessments of changes for the 25 countries of the European Union. Global economic and integrated assessment models (GTAP and IMAGE) were used to calculate changes in demand for agricultural areas at the national level, while a spatially explicit land use model (CLUE-S) was used to translate these demands into land use patterns (van Meijl et al., 2005).

The table below shows the area of the EU-25 facing urbanization, agricultural land abandonment, and/or new "natural land." The maps below illustrate how the incorporation of spatial policies results in very different land use patterns (1 × 1 km^2) for southern France. In the B2 scenario (Regional Communities), the Less Favored Areas (shaded areas in 2000 map which indicate areas of low productivity) are maintained leading to incentives for continuation of arable agriculture, thus slowing land abandonment in these areas. In the B1 scenario (Global Cooperation), the Less Favored Areas are only incentives for managed grasslands, which leads to an almost complete disappearance of agriculture in these areas. Thus, patterns of land use change are very different, although the overall percentage of change is similar.

Change in land use between 200 and 2030 (as percentage of total land area of EU-25)

	A1	A2	B1	B2
Urban land	2.4	1.4	1.3	0.4
Agricultural land abandoned	6.4	2.5	6.3	5.2
"Natural land"	2.1	0.6	4.6	3.2

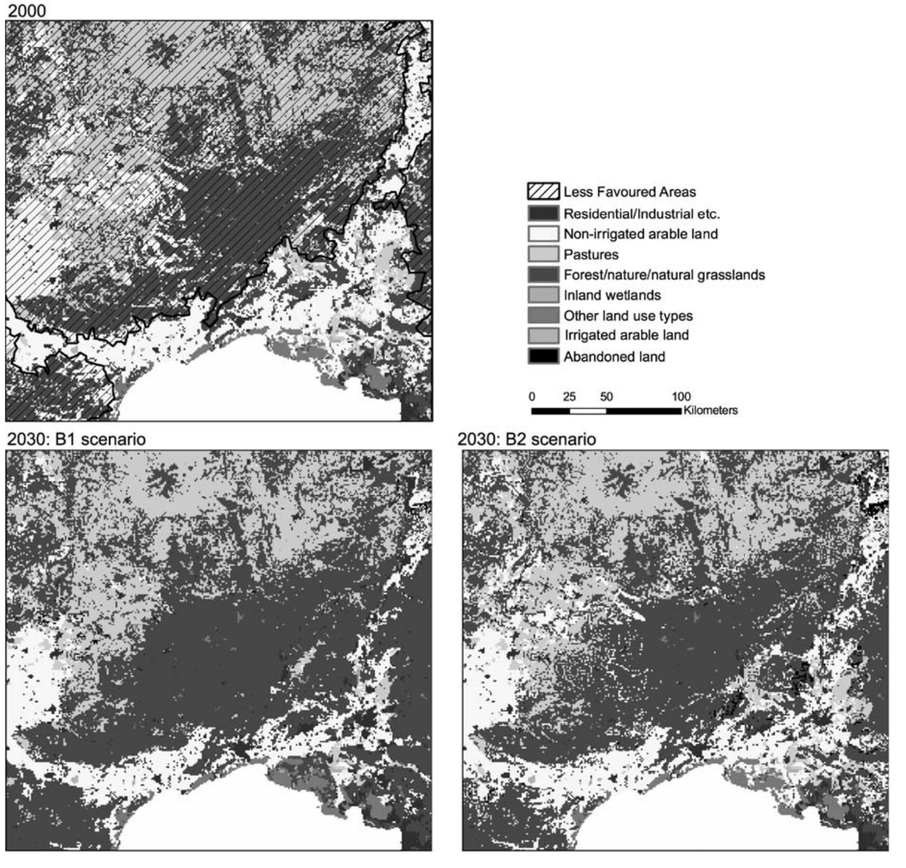
ratio = 0.95) and this will increase according to the scenarios by an average factor of 1.2 between 1995 and 2050, thus making Europe a net exporter of food products.

4. Regional and Local Scenarios

4.1 Methodological issues

The variety and number of regional and local land use scenarios is much larger than global scenarios. This variety is caused primarily by the much wider range of locally-specific questions that are being addressed and locally-specific factors deter-

Box 4.4 (*continued*)



mining land use and cover. Other causes are methodological problems mentioned earlier and varying availability of reliable data.

On the one hand, regional studies of future land use have objectives similar to that of global studies in that they also offer insight into the consequences of current actions and uncertainties of the future and thus support more informed and rational decision-making. On the other hand, while global studies tend to focus on producing scenarios, regional studies often concentrate on developing tools for direct decision support because in principle land use change can be steered by local stakeholders (see Peterson et al., 2003).

Regional scenarios also differ from global scenarios with respect to the basic questions they address. Whereas global scenarios tend to ask *how much* land use change will take place, regional scenarios tend to address *where* it will take place. Although Lambin et al. (2000) suggest that the magnitude of change might be more informative than its location, most regional scenario studies have in practice

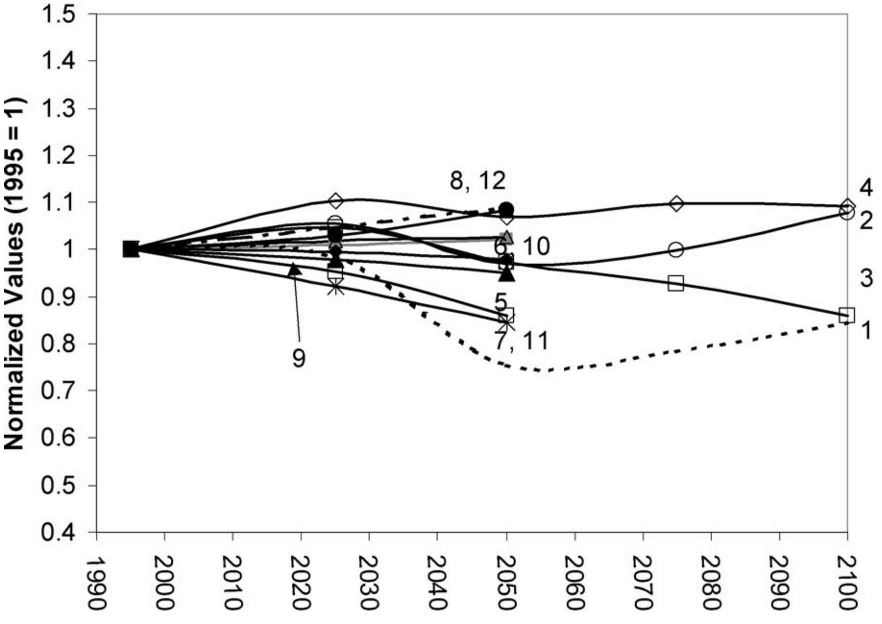


Figure 4.9 Scenarios of forest land in Europe from 1995 to 2100. The key to scenario numbers is the same as in Figure 4.8, except the scenarios 13 to 17 which do not contain forest land cover. "Forest land" is defined as in Figure 4.2.

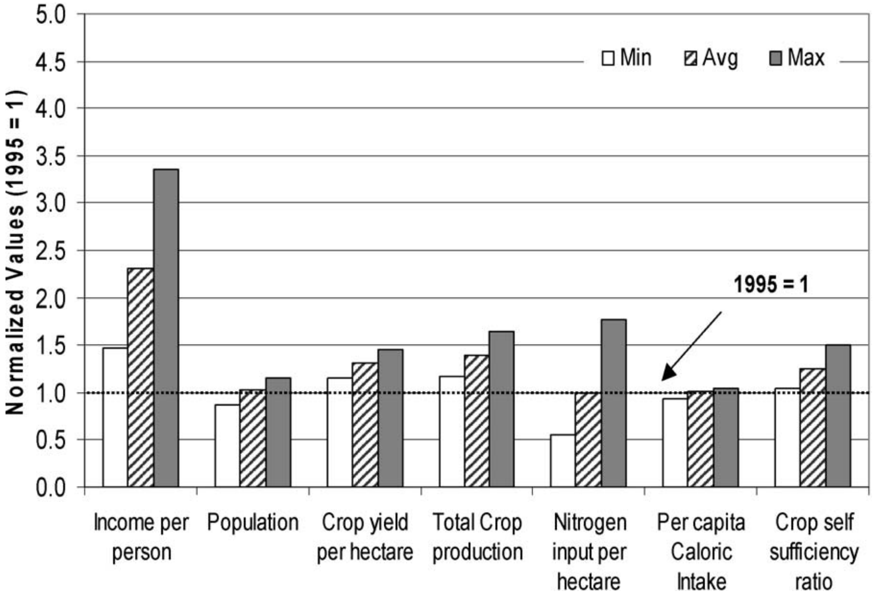


Figure 4.10 Drivers of scenarios of land use and cover in Europe from 1995 to 2050.

focused on the location of change and have employed spatially-explicit models to map this change. A typical procedure is to first develop storylines that specify the trends of socio-economic, environmental and institutional variables determining land use, as well as the resulting direction or even order of magnitude of land use change. Quantitative models are then used to allocate *where* the land use change will take place, consistent with the trends specified in the storyline.

The typical drivers included in regional and local scenarios are similar to those used in global scenarios but, of course, are described in much greater detail. In comparison to global scenarios, regional and local storylines often include governance issues, technology, and changes in the social system. These translate into similar quantitative drivers, although data on social issues are often limited and economic drivers (income, trade, subsidies, prices) dominate. The location of change is determined by a range of factors, including biophysical (for example topography, soil, and/or precipitation), demographic (population, accessibility), and socio-economic (land tenure, education level). The determining mix of factors depends on local characteristics. In Brazil, for example, the distance of development to road is very often the most important factor, boosted by the launch of the "Avança Brasil" which involves very high investments for road paving (e.g. Alves, 2001; Laurance et al., 2001). By comparison, European scenarios would not be complete without including the effects of the Common Agricultural Policy, while many studies single out soil characteristics as the main determinant of land use (e.g. Bakker et al., 2005).

Although the diversity of drivers is high, population is the single most frequently mentioned driving force, both in determining quantity and location of change (e.g. Kok, 2004). Published land use scenarios, however, still tend to simplify the impacts of population because of lack of data, despite a strong plea from the LUCC community that population will hardly ever be the key single driver (Lambin et al., 2001). Recently, more complex measurements of accessibility (Verburg et al., 2004), income and education level are being included in land use models.

In the following paragraphs we review a small selection of the many regional and local scenarios that have been developed. To minimize the problems of interpreting scenarios based on different methodologies, we review only the sub-set of scenarios which fulfill one or more of the following conditions: (i) They are embedded in regional and/or global developments (e.g. scenarios produced by the Millennium Ecosystem Assessment or EURURALIS); (ii) They were developed using a single framework/methodology applied at different locations (e.g. scenarios based on the CLUE, SLEUTH, or Environment Explorer models); (iii) They have employed a proven methodology such as the cellular automata approach; and/or (iv) They are considered "archetypal" scenarios for a particular location.

4.2 Results from regional and local scenarios

While most global/continental scenarios have a long perspective (usually up to 2050, some up to 2100), most regional/local scenarios are short term (usually up to 2015, some up to 2025). However, there are exceptions as we see later. Short-term scenarios tend to be extrapolations of current trends, while long term scenarios are usually derived from a top-down, multi-scale methodology and incorporate non-linear system changes and feedbacks. We begin with a review of short-term regional scenarios.

The picture that emerges from many short term studies is not encouraging from the point-of-view of environmental change. In Latin America, the vast majority of scenarios indicate that deforestation will continue unabated, although there are exceptions (e.g. Fearnside, 2003). Examples of regional deforestation scenarios are given in Box 4.5 Growing populations, expanding economies and increasing urbanization characterize the situation in Southeast Asia (Roetter et al., 2005). The few available regional scenarios for Africa (e.g. Thornton et al., 2003) suggest that further increases in population and income will change dietary preferences and boost food demand. Since increasing food demand cannot be easily covered by boosting crop productivity and imports and hence agricultural land will greatly expand. This is consistent with the results of most continental-scale African scenarios (Figure 4.5) which indicate a strong expansion of agricultural land over the coming few decades. However, as noted above, the continental scenarios show a slowing of this expansion and its eventual reversal over a longer time period.

In North America, the focus of land research has traditionally been on monitoring current land-use/cover change and describing historical changes, thus gaining understanding of the current patterns of land use and important (historical) drivers of change. Recently, however, the emphasis has shifted to scenario development. Examples are the work of spatial economists (e.g. Irwin and Bockstael, 2004); the use of agent-based models in the SLUCE project (Spatial Land Use Change and Ecological Effects at the Rural-Urban Interface, see Brown et al., 2004); and the applications of the urban growth model SLEUTH (Clarke and Gaydos, 1998). Land use research is coordinated in a number of research programmes, notably NASA's Land Cover Land Use Change Program (Gutman et al., 2004); the Human-Environment Regional Observatories (HERO); and the US Global Change Research Program Element, Land Use/Land Cover Change (USGCSP, 2003) with a particular emphasis on the future impact of climate change on crop productivity. It is to be expected that the number of land scenarios will increase rapidly in the near future.

Short term scenarios of European regions have analysed the impact of the recent expansion of the European Union from 15 to 25 countries (e.g. Kohler, 2004) and of the European Common Agricultural Policy of the European Union (see Topp and Mitchell, 2003; ACCELERATES, 2004). These scenarios indicate a continuation of urbanization and land abandonment, together with further land and water quality degradation.

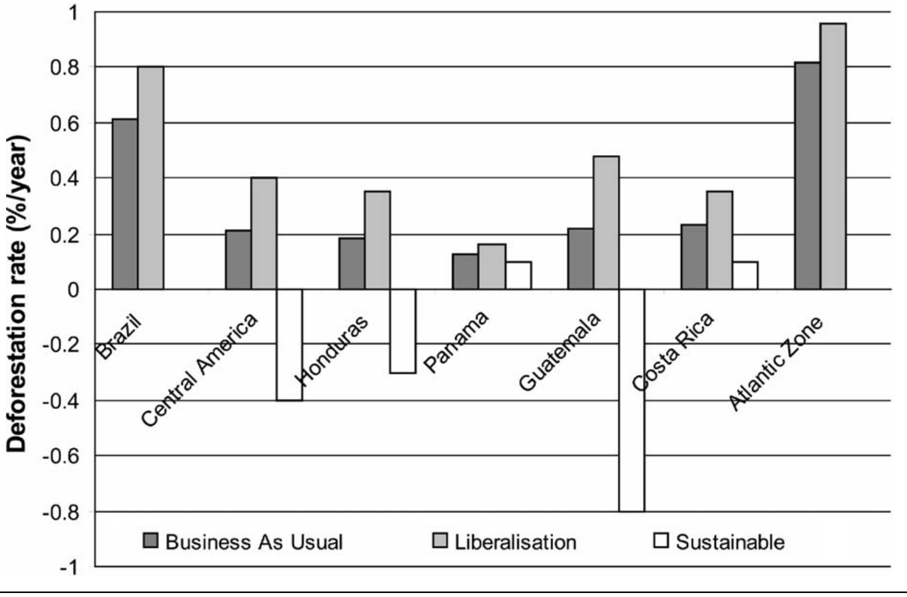
One set of long term studies of local land use changes have focused on potential changes in agricultural areas up to 2100. For example, as a result of climate change the corn and wheat belts in North America may shift northward, reducing US production of these crops and increasing their production in Canada (IPCC, 1997). These studies analyse potential impacts on land use, but do not provide an integrated view of land use changes incorporating socio-economic developments.

Another set of long term studies focus on downscaling and applying global scenarios to the regional and local scale. Many of these studies have downscaled the

Box 4.5 Scenarios (2000–2010) of deforestation in Central America.

The quantitative scenarios of deforestation in Central America depicted below were derived through a multi-step procedure. First, qualitative storylines for Central America were written based on information and requests from experts and decision makers (Business as Usual, Market Liberalization, Sustainability). The storylines were then quantified using FAOSTAT data. Finally, these data were input to the CLUE model (Verburg et al., 1999) that produced quantitative estimates of deforestation (Kok and Veldkamp, 2000; Kok and Winograd, 2002).

The bar graph below shows that deforestation rates remain high between 2000 and 2010. Although national level rates are lower in Central America than in the Brazilian Amazon, local rates (e.g. the Atlantic coast of Costa Rica) are as high. The "Sustainable" scenario was formulated at the request of national policy makers and is a normative scenario. Despite the strong interest in a scenario with a reversal of deforestation, the quantification of this scenario indicated that deforestation is likely to continue in the short run in Costa Rica and Panama. During quantification it was assumed that "sustainability" measures (e.g. institutionalization of national parks, and changes in dietary patterns) only occur when the economy grows fast and human well-being is increased. But higher income and well-being also stimulate a higher demand for beef which leads to an expansion of grazing land, and hence to continuing deforestation. Moreover, the sustainability scenario was not considered feasible by experts and decision makers involved in the scenario studies because it assumed that current trends of land use policies, dietary patterns, and crop yield could be reversed within the next decade.



IPCC SRES scenarios (IPCC, 2000a). These include the work of the ATEAM project (Rounsevell et al., 2005) and the EURURALIS project mentioned earlier (Klijn et al., 2005; see Box 4.4). Other examples are the application of SLEUTH in the US (Solecki and Oliveri, 2004); land use scenarios for the Netherlands (Kuhlman et al., 2005; de Nijs et al., 2004); and a local landscape study in Norfolk, England (Dockerty et al., 2005).

An important characteristic of regional and local scenarios is that they sometimes show solutions to global change problems that are overlooked by the coarse resolution of global scenarios. For example, local policies may effectively slow down deforestation in Brazil (Fearnside, 2003), and crop-farming can be replaced by fish-farming in flooded areas in the Netherlands (White et al., 2004). Such local solutions could have a global impact if they propagate throughout the world.

4.3 Results from urban scenarios

The analysis of spatial developments in urban areas has proceeded separately from the regional and local studies mentioned above, and merits a separate discussion. The most common approach used for producing urban scenarios is cellular automata modeling because of its flexibility in handling "rules" that determine changes in urban areas. Other approaches include the "land transformation model" of Pijanowski et al. (2002) and the agent-based model of Brown et al. (2004).

Up to now, urban scenarios have concentrated on future expansion of urban land, an important issue in both developed and developing countries. Over the last decades urban populations in developed countries have been moving from dense, compact urban centers to new low-density urban areas on the outskirts of present cities. Meanwhile, a combination of high population growth and lack of (urban) planning has led to a large expansion of urban land in many developing countries. One of the main messages of urban scenarios is that urban land will continue to expand at many different locations. Some scenario studies (e.g. Pijanowski et al., 2002) also suggest that the expansion of urban area may lead to a greater-than-proportional loss in fertile farmland – New urban areas not only occupy the best agricultural lands but also attract industry and infrastructure that claim an additional share of former rural land. These changes are of particular importance since they are usually irreversible over a long time period.

Scenario analysis has also shown that urban sprawl, and its opposite "compact growth," could lead to many different plausible spatial patterns of urban growth. The recent EURURALIS project (Klijn et al., 2005) considered different variants of sprawl- and compact-type growth in European cities (Table 4.1) and found that factors such as local city planning policies have an important effect on the particular spatial pattern resulting from sprawl or compact growth. The EURURALIS scenarios also indicated that urbanization rates are likely to remain high until 2030 under the downscaled assumptions of the four IPCC-SRES scenarios (IPCC, 2000a) (Table 4.1). Solecki and Oliveri (2004) reached similar conclusions for the New York Metropolitan Region by downscaling two of the same four IPCC-SRES scenarios.

Table 4.1 Assumptions for characteristics of urban growth in the EU-25 between 2000 and 2030 from EURURALIS Project. Scenarios are downscaled urban versions of the IPCC-SRES (IPCC, 2000a) storylines

	A1	A2	B1	B2
Type of urban growth	Sprawled	Sprawled	Compact	Compact
Large cities	No restrictions	No restrictions	Designated areas only	Designated areas only
Provincial towns	No incentives or restrictions	No incentives or restrictions	Designated areas only	Designated areas only
Small villages	Proliferation of second houses	Decrease in land abandonment regions	Designated areas only	Maintain size and structure

4.4 Results from multi-scale scenarios

The close connection between future land use on the global and regional scales argues for the development of integrated global-regional land use scenarios. The Millennium Ecosystem Assessment (MA) took first steps in this direction by constructing parallel global and regional land use scenarios as part of their multi-scale assessment of ecosystem services (MA, 2003). The MA effort provides experience on how to set up a multi-scale scenarios exercise. Figure 4.11 shows two different multi-scale organizational structures used in the MA, a fully hierarchically nested design (southern Africa) and a partly nested design (Portugal). Two parallel scenario exercises were conducted. On the global level, a global scenarios team developed

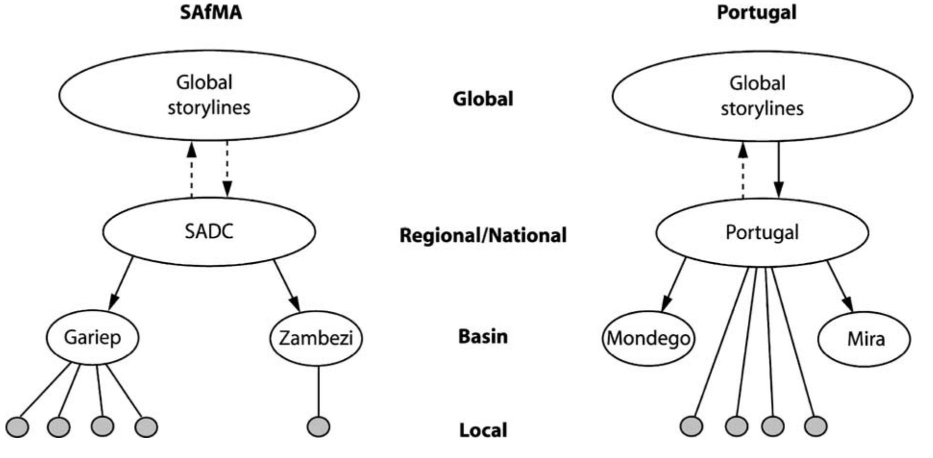


Figure 4.11 Multi-scale designs of two "sub-global" assessments of the MA. SafMA – Southern Africa Millennium Assessment, SADC – Southern Africa Development Community.

four scenarios, which can be described by two axes of uncertainty (global versus regional development, and proactive versus reactive actions relative to environmental degradation). To drive the scenarios a set of global driving forces with country-scale resolution were selected. On the regional level different regional scenario teams developed regional scenarios using the driving forces from the global scenario exercise as one of many inputs to their scenarios. While the global scenario exercise provided input to the regional scenarios, the regional scenarios were completed too late to provide feedback to the global scenarios.

Experience from the Portugal scenario exercise illustrates the difficulty in harmonizing regional and global scenarios. The global scenario "Global Orchestration" reflects a world of economic optimism in which farming areas are mostly located where production is highest and most efficient. When translated to Portugal by the regional scenarios team, this scenario described a future in which regional agriculture is abandoned and replaced by oak forests, rural population migrates to cities and the expansion of uncultivated land leads to greater biodiversity. While international stakeholders consider Global Orchestration as a desirable scenario, Portuguese policy-makers had the opposite view because of the loss of rural employment and economic activity.

The Visions project (Rotmans et al., 2000) is another example of multi-scale scenarios, this time at the pan-European and local scales. Scenarios were first developed independently at the two scales and then mapped onto each other. Local scenarios tended to be generally positive and include local solutions to future challenges because of the multi-scale design (which encourages broad global and local thinking) and because of the involvement of stakeholders (who were interested in local solutions). In the Green Heart region in the Netherlands, for instance, agricultural entrepreneurs exploit more frequent extreme rainfall events and flooding by shifting their future focus to fish-farming (see White et al., 2004). In a subsequent project (MedAction; de Groot and Rotmans, 2004) the three European scenarios were translated to fit land use issues (Kok et al., 2003) and were downscaled to the Mediterranean region (Kok and Rothman, 2003). Again, local scenarios tended to be a mix of higher-level changes and local innovative solutions. In the Guadalentín in Spain, water transport networks are projected to sustain agriculture, while in the Agri Valley ecotourism is integrated with small-scale agriculture (Kok and Patel, 2003).

The MA and Visions scenario exercises are just two of an increasing number of multi-scale scenario exercises. As mentioned earlier, many groups are downscaling global scenarios from the Intergovernmental Panel on Climate Change (IPCC, 2000a), the Millennium Ecosystem Assessment (MA, 2003) and the Global Environmental Outlook of UNEP (UNEP, 2004). One point of view is that downscaling a limited set of global scenarios is better than a "bottom up" approach in which stakeholders help to develop local scenarios, in that downscaling provides a common, consistent framework for scenarios at many different locales and regions (e.g. time horizon, time steps, categories of driving forces, definitions of land use terms). Thus it makes the scenarios from these places more comparable.

Another point of view is that global downscaling limits the creativity and diversity of regional scenarios. An example of this can be found in a number of downscaling efforts in Europe. The "Less Favored Areas" are defined as agricultural areas that are economically marginal. Therefore, they provide a useful spatial indicator of non-optimal production areas (Rounsevell et al., 2005). This idea was implemented in a similar fashion in several studies – in the ATEAM studies (Rounsevell et al., 2005), in EURURALIS (Box 4.4), in applications of the Land Use Scanner (Kuhlman et al., 2005) and in applications of the Environment Explorer (de Nijs et al., 2004). All these studies downscaled continental or global scenarios and used the Less Favored Areas concept as a means to make the effect of the Common Agricultural Policy spatially explicit. Because spatial policies strongly and directly affect land use patterns, these similarities carried over in the resulting land use maps. The influence of the continental or global scenarios might be overly strong, thus weakening the local and regional signals. Based on the authors' experience, regional scenario exercises that emphasize stakeholder participation tend to stress local and regional factors and produce more diverse results.

To sum up, the multi-scale approach seems to be a promising method to standardize and harmonize local, regional and global studies, but it has only recently been given adequate attention. Many more studies are needed before any final conclusion on its usefulness can be drawn.

5. Main Findings of Scenarios

Although the scientific community is only beginning to study the future of land, the existing set of scenarios offers interesting insights to researchers. These scenarios range from the global/continental to regional/local and take the form of qualitative "storylines" and/or quantitative model output. The set of existing scenarios cover a wide variety of possible driving forces up to 2100. They present "not implausible" futures of land use without making assertions about the probabilities of these futures.

There are some notable differences between global and regional scenarios. The published global scenarios have been based on only two modeling approaches – accounting and rule-based/cellular automata models while the regional scenarios have used a wider variety of approaches. The global scenarios tend to be more expert driven, and cover a smaller set of potential futures than the regional scenarios. Global scenarios tend to be long term, while regional scenarios tend to be short term. Most of the global scenarios derived up to now mostly follow a few archetypical ideas of coming developments such as the continuation of current globalization trends or the reversal of globalization and collapse of international cooperation. Regional scenarios, because of their focus on smaller and more specific localities or regions, have tended to be more stakeholder driven. For these reasons they also encompass a larger variety of views of the future, including the potential influence of local policy and institutions. However, it is usually difficult for developers of regional scenarios to set the physical/political boundaries of their scenarios, whereas developers of global scenarios do not have this problem. Global scenarios, by nature, focus on international, large-scale solutions to undesirable global change, while regional scenarios illustrate local solutions that may be overlooked by the coarse resolution of global scenarios.

Taken together, current land scenarios support the idea that fine, "local" spatial patterns of land use change tend to be determined by local factors (e.g. city planning policies, local recreational preferences or topography), while the overriding forces for change come from outside drivers (e.g. world food trade, or society-wide changes in food preferences). This perspective is implicit in many scenarios and has an important influence on their results. The validity of these assumptions should be checked with empirical data.

The diversity of regional and local land use scenarios makes it difficult to summarize their main findings. But in their diversity may lie their strength in that regional and local scenarios provide a rich variety of different "bottom-up" views of the future. Nevertheless, constraining the range of regional and local scenarios by downscaling them from global scenarios has the advantage of making local land use scenarios more consistent and comparable. The relative benefits and costs of these two approaches must be further discussed. It may even be possible to link global and regional scenarios in a way so that both gain from the other (see "Towards Better Land Scenarios").

Changes in extent of urban land

Scenarios have been developed for both the sum of global/continental changes in urban area, as well as for changes in the area of individual cities. The published scenarios of both types indicate a continuing increase in urban area over the decade 2000–2010, but some scenarios show a stabilization of global urban area by 2025. We remind the reader that scenarios are if-then propositions of what could occur given certain assumptions, and that different population, economic, and other assumptions could lead to scenarios of decreasing urban area. Nevertheless, for the range of assumptions adopted in the literature, urban area shows a global increase over at least the coming decade.

Regional and local scenarios also show that urbanization could lead to many different fine-scale patterns of land use in metropolitan areas. Some scenarios also show that fertile agricultural land could disappear at a faster rate than the expansion of urban area because of the additional infrastructure and other land requirements of the urban population.

Changes in extent of agricultural land

The focus of most scenarios is on changing agricultural land, probably because agriculture is so important economically and politically. Many scenarios emphasize the link between deforestation and agricultural land. The great majority of both regional and global scenarios indicate an expansion of agricultural land over the next decade, with the biggest changes occurring in the tropics. But many global scenarios also show turning points at which the trend in agricultural land changes its direction some time between 2010 and 2050. Many African scenarios point to an eventual slowing of population growth and technological "catch-up" which accelerates improvements in crop yield. The net effect is a shift from expanding to contracting agricultural land. If realized, this reversal in trends could relieve some of the pressure on existing unmanaged natural land and have positive consequences for biodiversity.

Although turning points are not implausible, up to now they have only been generated as a consequence of the input assumptions of scenarios and hence require empirical validation. Indeed, both scenarios and models require more rigorous descriptions of the future impacts of increasing food demand and depletion of suitable agricultural land. Another key uncertainty has to do with the way in which future food demand will be satisfied – Will it be by expanding agricultural land, by intensification of existing land, or by world food trade? Much more research work is needed on this issue so that agricultural scenarios can capture a fuller range of possible futures.

Changes in extent of forest land

The majority of regional scenarios indicate a continued rapid deforestation in many parts of Africa and Latin America over the next decade. Most global scenarios also show this short-term trend, but in addition suggest an eventual slowing of deforestation after a few decades as a result of the slowing of agricultural land expansion. This has important implications for carbon dioxide fluxes and other global change processes. Some scenarios for Africa even show a relatively rapid reversal of deforestation, which raises the interesting question, is it ecologically feasible for tropical forest ecosystems to re-establish themselves within a few decades suggested by these scenarios?

Large-scale forest scenarios tend to mirror agricultural scenarios in that forest land coverage is determined mostly (in the scenarios) by the expansion or contraction of agricultural land. This, of course, is an exaggerated simplification of reality, and future scenarios must take into account other factors that influence forest land such as conventional management practices (e.g. wood extraction), unconventional management practices (e.g. plantations for carbon sequestration), and protected areas of forests. Moreover, most existing global and regional scenarios do not distinguish between primary and secondary forests, which play different roles in the regulation of the water cycle, the support of species, and other global change processes.

Consequences for the earth system

Taken together, the set of published scenarios imply that major changes in the earth's land cover over the next decades are not implausible. These changes have large implications for the global water system (through modification of moisture and energy fluxes), for the rate of climate change (through changes in various climatic processes and in emissions of methane, nitrous oxide and other greenhouse gases), for biodiversity (through impacts on the integrity of habitats), for the global carbon cycle (through modifications in terrestrial carbon fluxes), and for other aspects of the earth system.

6. Towards Better Land Scenarios

Although existing scenarios have served the needs of different audiences from local farmers to global policy makers, we have pointed out in the previous text that there are substantial opportunities for improvement. But what direction should these improvements take? We suggest that goal of improvements should be to enhance the following four characteristics of scenarios. (This list builds on the three criteria (salience, credibility, legitimacy) for quality control of integrated assessment presented by Jill Jäger at the Workshop on "Scenarios of the Future, the Future of Scenarios," Kassel, Germany, July, 2002.)

- *Relevance* – Is the scenario relevant to its audience? Are the particular needs of the potential users addressed? The range of audiences for land scenarios is very wide, extending from the community interested in global change processes (and land use/cover change, in particular), to the concern of regional planners about local land use changes.
- *Credibility* – Is the scenario plausible to its principal audience and developers? Are the statements and causal relationships consistent with existing information? Are the assumptions about the causal relationships underlying the qualitative scenarios (mental models) or quantitative scenarios (formalized models) transparent? Is the scientific rigor and methods used to develop the scenarios acceptable? Is the credibility of scenario developers high enough?
- *Legitimacy* – Does the scenario reflect points of view that are perceived to be fair by scenario users, or does the scenario promote particular beliefs, values or agendas? Was the process for developing scenarios perceived to be fair? Are the process and results adequately documented? (These factors are also important to the credibility of scenarios.)
- *Creativity* – Do the scenarios provoke new, creative thinking? Do they challenge current views about the future? (If this challenge is justified.) Do they inform their audience about the implications of uncertainty?

The following paragraphs propose a range of actions for producing better scenarios by enhancing these characteristics.

1. Expand the scope of scenarios

While existing scenarios cover some of the basic dynamics of changing land use and cover, they still incorporate only a small fraction of the processes determining these dynamics. An important way to improve the *credibility* and *relevance* of scenarios would be to expand their scope to include more land use/cover processes. By including more processes the scenarios will gain scientific *credibility* because they are more likely to capture the driving forces and dynamics that will determine future land use/cover changes. Likewise, covering more processes will make the scenarios more *relevant* to a wider range of scientific and policy users.

In the following paragraphs we recommend six priorities for expanding the scope of scenarios.

- *Describe in more detail the factors determining the extent of future agricultural land*. As noted earlier in this chapter, most land scenarios focus on agricultural land because of its economic and political importance. However, most of these scenarios are based on simplified assumptions about future farm management, crop yield and other factors that will determine the extent of future agricultural land. The credibility and relevance of agricultural land scenarios would be enhanced if scenario builders provided a more detailed rationale for future trends in these factors. In particular, scenario builders should draw on either conceptual or formalized models to estimate future productivity of crop and grasslands, the future importance of new crops such as bio-energy plants, and the tradeoff between future agricultural intensification and extensification.
- *Give more attention to non-agricultural land*. While the current focus of scenarios on agricultural land is understandable, neglecting other types of land results in an incomplete picture of future land use and cover. Land cover with natural vegetation (forests, grasslands) is often treated in scenarios as a remnant land cover classes (areas not needed for other purposes). Hence greater attention should be given to future changes of non-agricultural land (forest, grassland, urban). In addition, more attention should be given to realistically representing competition between land cover types since many future policy interventions affect the availability of land (conservation of nature, carbon plantations, livelihood of rural areas, renewable energy etc.).
- *Incorporate more detail about driving forces*. Most land scenarios are driven by assumptions about external factors such as population, economic growth, and technological development. Although these factors are usually prescribed *ad hoc*, the reality is that they are affected by a host of other factors. The realism of land scenarios, and thereby their credibility and relevance, would be enhanced by including more detail and realism about future trends in these driving forces. Examples are:
  - The effect of social and cultural attitudes on food consumption, on land use practices (e.g. farming systems), and on the priority given to the conservation of natural resources.
  - The impact of labor, capital and global food trade on agricultural production.
  - The effect of traditions and practices of land tenure on land use patterns.
  - The effect of shifts of population from rural areas to urban or vice versa.
- *Incorporate feedbacks into driving forces*. In reality not only is land use driven by external factors, but land use change in turn affects feeds back to these external factors. An example of such a feedback was given in Section 1.3.2. A key task for scenario developers is to incorporate the feedback from land use change to external drivers, drawing on new knowledge about these feedbacks. This task can be achieved by modifying the models used to generate the scenarios. One way to modify the models would be to convert external drivers into internal variables in the model. Another way is to insert a switch in the model that indicates when "unrealistic" land use change is computed. This switch would then send a signal to automatically modify the external drivers so that more "realistic" land use change is computed.

- *Include extreme events and changes in their periodicity*. It is generally understood that flooding, fire and other extreme events have a profound but transient impact on land use and land cover (e.g., Kauffman, 2004; Kok and Winograd, 2002; Cochrane et al., 1999). At the same time a single event usually does not have a persistent effect on land cover over the scale of several years because vegetation and ecosystems tend to re-establish themselves after such events. But it is also observed that *recurrent* extreme events can have an important influence on permanent land cover (e.g., Nepstad et al., 2004; van Noordwijk et al., 2004; Sorrensen, 2004; Correia et al., 1999). One example is the role of periodic brush fires in determining the vegetation in chaparral landscapes. Hence rather than including *single* extreme events in scenarios, it would be more consistent with current thinking to include a *change in periodicity* of extreme events (if appropriate for the setting of the scenarios). Including extreme events in this way could make them more thought provoking and thereby enhance their creativity.
- *Inform stakeholders about the limitations of models*. A problem related to the limited scope of models is the communication problem that arises when stakeholders specify that a land scenario has 15 driving forces, but the model used to quantify the scenarios can only handle 5 of these driving forces. This is just one of the many mismatches that typically occur between the mental models of stakeholders and the simpler formalized models used for quantification of scenarios. This mismatch takes away from the consistency and credibility of the scenarios. In this case a partial solution is simple – The model teams should inform stakeholders about the limitations of the models at an early stage of scenario development. The stakeholders then have the option of taking into account these limitations. Another option is to use simple, flexible models that can be adjusted quickly to the specifications of stakeholders during a scenario exercise.

2. Use participatory approaches to scenario development

We believe that the *relevance*, *legitimacy* and *creativity* of scenarios can be enhanced by developing them in partnership with stakeholders (i.e. individuals or organizations with a special interest in the outcomes of the scenarios). This is called the "participatory approach" to scenario development, as described earlier in the chapter. Typical of this approach is the use of a scenario panel consisting of stakeholders and experts to carry out the core work of scenario development.

How does the participatory approach enhance the *relevance*, *legitimacy* and *creativity* of scenarios? By including some of the potential users of the scenarios in the scenario panel (the stakeholders), the scenarios have a higher chance of addressing *relevant* policy questions. Since these stakeholders represent the different interest groups concerned with scenario outcomes, their participation also enhances the *legitimacy* of the scenarios. The participatory approach can also produce more *creative* scenarios because the wide range of views represented on the scenario panel often lead to new combinations of views about the future that are incorporated into less conventional and more creative scenarios.

However, a key to making scenarios more relevant, legitimate and creative is to ensure that the scenario panel is made up of a wide, and representative group of stakeholders and experts. Otherwise the scenario panel may be perceived as being biased towards one interest or another, thus undermining the credibility and legitimacy of the scenarios they produce. Moreover, a scenario panel with biased views will also narrow the scope and creativity of the scenarios they generate.

3. Improve the transparency and documentation of scenarios

In this paragraph we return to the question of how to maximize the *credibility* of scenarios. Sometimes credibility is associated with likelihood (the more likely a scenario, the higher its credibility) but this does not always hold for scenarios for two reasons. First, information about the likelihood of a scenario is usually not available. (For example, the authors of the IPCC emission scenarios explicitly advise scenario users that no likelihood should be assigned to the different scenarios; IPCC, 2000a.) Second, even unlikely scenarios can serve a useful purpose, as in the case of low-probability scenarios of accidents in nuclear power plants which are useful for developing accident contingency plans. Hence, the *credibility* of a scenario is not always related to its likelihood.

As an alternative, we believe that the *credibility* of a scenario can be associated with its internal logic, consistency and coherence. That is, the more logical, consistent and coherent the scenario, the higher its credibility. In turn, this logic, consistency and coherence must be "transparent" through the clear documentation of a scenario's basic assumptions, internal structure, and driving forces. This is a special challenge for qualitative scenarios because they are usually expressions of the complex mental models of stakeholders. To make the assumptions behind these scenarios more transparent it may be possible to use well-established techniques of "soft systems research" that formalize human thinking and decision processes (e.g. Fishwick and Luker, 1991; Checkland, 1981). Another possible approach is to use spatial and/or historical analogs of the events in a scenario. In the case that models are used to generate scenarios, the credibility of the scenario can be enhanced by documenting the model and its assumptions in peer-reviewed scientific literature.

4. Build interactive scenarios

Another approach to increase the *credibility* of scenarios is to build "interactive" scenarios. This type of scenarios would increase the credibility of scenarios in general because they provide a more realistic representation of the driving forces of scenarios.

Under this procedure the time horizon of the scenario exercise (say 2005 to 2100) would be divided into smaller intervals (e.g. 2005 to 2020, 2020 to 2050, and 2050 to 2100). Rather than specifying driving forces over the entire time horizon as is usually done, the driving forces would be specified only for the first time interval. The next step would be to evaluate the consequences of these driving forces on land use/cover for the first time interval (either with a model or with storylines). The results of the first interval would then be used to set the starting conditions for the second interval. For example, if agricultural land in a study region is depleted by the end of the first scenario interval, this information could be used to assume a higher rate of migration from rural to urban areas in the second interval. In effect, the scenario developers would "interact" with the scenario itself, and would specify the feedback from land use to driving forces. Rather than being specified only one time at the beginning of the scenarios, the driving forces would "interact" and be modified by the dynamics of the scenario.

A disadvantage of this method is the large effort it requires. We also note that the idea of interactive scenario development resembles the procedures of strategic gaming and "policy exercises" applied earlier to environmental and other problems (Checkland, 1981; Fishwick and Luker, 1991; Toth, 1988, 1995).

5. Broaden the realm of application of global scenarios

An obvious way to increase the *relevance* of scenarios is to develop them for addressing a wider range of scientific and policy questions. Most existing global land scenarios were developed for analyzing climate change issues such as the emissions of land-related greenhouse gases or the flux of carbon dioxide between the atmosphere and biosphere. As a result they have a bias towards processes important to climate change and this limits their relevance to other issues. Global scenarios could also be developed for analyzing other important issues such as the consequences of trade liberalization, or the planning of "nature corridors" for increasing the connectivity of protected areas. Land scenarios could also contribute to strategies for achieving the land-related Millennium Development Goals (such as the goal to reduce world hunger) and for analyzing the implementation of the terrestrial aspects of the Convention on Biodiversity (see, e.g., Leemans, 1999). These applications will require an extension of the driving forces and processes covered by the scenarios.

6. Develop multi-scale scenarios

In this paragraph we recommend developing multi-scale scenarios as a way of enhancing the *credibility* and *relevance* of scenarios in general. We noted earlier that existing global and regional scenarios tend to provide different kinds of information. Global scenarios provide a comprehensive picture of the implications of large-scale driving forces on land use and cover change, while regional scenarios provide a more detailed representation of land use/cover changes which can be related more realistically to biogeochemical processes such as soil degradation, changes in hydrology and land processes leading to emissions of greenhouse gases. Both types of scenarios lack a measure of *credibility* and *relevance* because they cannot capture the view of the others, and would gain *credibility* and *relevance* if they could be linked.

In the text we referred to various efforts at developing multi-scale scenarios. A possible linkage would be to use global scenarios for setting boundary conditions and constraints for regional scenarios, e.g. the demands of global food markets or the implementation of national/international nature conservation goals. In the other direction, regional scenarios covering different parts of the world could provide input that is difficult to capture at the global scale. Some examples are the impact of land-related institutions (farming associations or regional planning organizations) on land use change, visions of regional development pathways, the influence of cultural background on land use practices, and attitudes towards nature protection.

7. *Improve the representation of socio-economic behavior in scenarios*

Here we recommend increasing the *credibility* and *creativity* of scenarios by improving the representation of socio-economic behavior in scenarios, especially by applying agent-based modeling. Agent-based models have been used for simulations at the local and regional scale and have a high potential for use in the development of land scenarios at all scales (see Chapter 7). They provide a method to improve and formalize (in the sense of making more transparent and traceable) important social processes in scenarios, and thereby will increase the *credibility* of scenarios. For example, agent-based models can provide insight into interactions between actors relevant to land use change such as between farming groups and the local government. Such approaches may also allow scenarios to incorporate the types of feedback processes that are currently poorly represented (as discussed above). This includes, in particular, processes that relate to policy-making and institutional responses to emerging environmental problems. By providing a platform for representing different ideas policy responses, agent-based modeling can also help produce more *creative* scenarios. But much work has to be done to enable the use of agent-based modeling or its results on the global level.

7. Closing Remarks

Summing up, although we are only in the early stages of analyzing the future state of land use and land cover on earth, we have already learned much from existing scenarios. One clear message of the scenarios of particular importance to global change is that current land use/cover patterns are not static. Indeed major changes in the earth's land cover over the next several decades, including trend reversals, are not implausible. The fact that some scenarios only begin to show distinctive trends after two or three decades also implies that a long term view is needed to better anticipate the future of land.

Although we have not evaluated the impacts of potential changes in land use and cover, we believe that the scale of changes shown in the scenarios could have large implications on the earth system. For that reason alone we should devote greater effort to understanding the future of land.

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REFERENCES

ACCELERATES, 2004. Assessing climate change effects on land use and ecosystems from regional analysis to the european scale. Section 6: Final report. Louvain-la-Neuve, Belgium. Retrieved 01.09.05 from http://www.geo.ucl.ac.be/accelerates/.

Achard, F., Eva, H.D., Stibig, H.J., Mayaux, P., Galego, F., Richards, T., Malingreau, J.P., 2002. Determination of deforestation rates of the world's humid tropical forests. Science 297, 999–1002.

Achard, F., Eva, H.D., Mayaux, P., Stibig, H.J., Belward, A., 2004. Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s. Global Biogeochemical Cycles 18, doi:10.1029/2003GB002142. GB2008.

Alcamo, J., 2001. Scenarios as tools for international environmental assessment. Environmental Issue Report No. 24, European Environment Agency, Copenhagen, Denmark, 31 pp.

Alcamo, J., Kreileman, G.J.J., Leemans, R. (Eds.), 1998. Global Change Scenarios of the 21st Century. Pergamon/Elsevier Science, Oxford, 296 pp.

Alves, D.S., 2001. Space–time dynamics of deforestation in Brazilian Amazonia. International Journal of Remote Sensing 23, 2903–2908.

Bakker, M.M., Govers, G., Kosmas, C., Vanacker, V., Van Oost, K., Rounsevell, M., 2005. Soil erosion as a driver of land-use change. Agriculture Ecosystems & Environment 105, 467–481.

Brown, D.G., Page, S.E., Riolo, R., Rand, W., 2004. Agent-based and analytical modeling to evaluate the effectiveness of greenbelts. Environmental Modelling & Software 19, 1097–1109.

Checkland, P., 1981. Systems Thinking, Systems Practice. John Wiley & Sons, London, UK, 416 pp.

Clarke, K.C., Gaydos, L.Y., 1998. Loose-coupling a cellular automaton model and GIS: Long-term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Science 12, 699–714.

Correia, F.N., Saraiva, M.D., Da Silva, F.N., 1999. Floodplain management in urban developing areas. Part I. Urban growth scenarios and land-use controls. Water Resources Management 13, 1–21.

Cochrane, M.A., Alencar, A., Schulze, M.D., Souza, C.M., Nepstad, D.C., Lefebvre, P., Davidson, E.A., 1999. Positive feedbacks in the fire dynamic of closed canopy tropical forests. Science 284, 1832–1835.

Dockerty, T., Lovett, A., Sünnenberg, G., Appleton, K., Parry, M., 2005. Visualizing the potential impacts of climate change on rural landscapes. Computers, Environment and Urban Systems 29 (3), 297–320.

Eickhout, B., van Meijl, H., Tabeau, A., van Rheenen, T., 2007. Economic and ecological consequences of four European land-use scenarios. Land Use Policy 24 (3), 562–575.

FAO (Food and Agriculture Organization of the United Nations), 1999. State of Food and Agriculture 1999. Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization of the United Nations), 2000. Agriculture: Towards 2015/30. Technical Interim Report, April 2000. Food and Agriculture Organization of the United Nations, Rome.

FAO (Food and Agriculture Organization of the United Nations), 2003. State of the World Forests 2003. Food and Agriculture Organization of the United Nations, Rome.

Fearnside, P.M., 2003. Deforestation control in Mato Grosso: A new model for slowing the loss of Brazil's Amazon forest. Ambio 32, 343–345.

Fishwick, P., Luker, P. (Eds.), 1991. Qualitative Simulation Modeling and Analysis. Springer-Verlag, Berlin, Germany, 341 pp.

Gallopin, G., Raskin, P., 2002. Global Sustainability: Bending the Curve. Routledge, London, UK, 232 pp.

Gallopin, G., Hammond, A., Raskin, P., Swart, R., 1997. Branch Points: Global Scenarios and Human Choice. PoleStar Series Report, No. 7. Stockholm Environment Institute – Boston, Boston, United States.

de Groot, R.S., Rotmans, J., 2004. MedAction. Final Report. Key Action 2: Global Change, Climate and Biodiversity; Subaction 2.3.3 Fighting Land Degradation and Desertification within the Energy, Environment and Sustainable Development. Contract No. EVK2-CT-2000-00085. ICIS, Maastricht.

Gutman, G., Janetos, A.C., Justice, C.O., Moran, E.F., Mustard, J.F., Rindfuss, R.R., Skole, D., Turner II, B.L., Cochrane, M.A. (Eds.), 2004. Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface. Remote Sensing and Digital Image Processing Series, vol. 6. Springer-Verlag, New York, 461 pp.

IMAGE-Team, 2001. The IMAGE 2.2 implementation of the SRES scenarios. A comprehensive analysis of emissions, climate change and impacts in the 21st century. RIVM CD-ROM publication 481508018, National Institute for Public Health and the Environment, Bilthoven, The Netherlands.

IPCC (Intergovernmental Panel on Climate Change), 1997. Special Report on the Regional Impacts of Climate Change. An Assessment of Vulnerability. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change), 2000a. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change), 2000b. Land Use, Land-Use Change, and Forestry. Special Report of the IPCC. Cambridge University Press, Cambridge, UK.

Irwin, E.G., Bockstael, N.E., 2004. Land use externalities, open space preservation, and urban sprawl. Regional Science and Urban Economics 34, 705–725.

Kauffman, J.B., 2004. Death rides the forest: Perceptions of fire, land use, and ecological restoration of western forests. Conservation Biology 18, 878–882.

Kemp-Benedict, E., Heaps, C., Raskin, P., 2002. Global Scenario Group Futures. Technical Notes. SEI PoleStar Series Report (revised and expanded), No. 9. Stockholm Environment Institute – Boston, Boston, United States.

Klijn, J.A., Vullings, L.A.E., Van de Berg, L.A.E., Van Meijl, H., Van Lammeren, R., Van Rheenen, T., Eickhout, B., Veldkamp, A., Verburg, P.H., Westhoek, H., 2005. EURURALIS 1.0: A scenario study on Europe's Rural Areas to support policy discussion. Background document. Wageningen University and Research Centre/Environmental Assessment Agency (RIVM).

Kohler, W., 2004. Eastern enlargement of the EU: A comprehensive welfare assessment. Journal of Policy Modeling 26, 865–888.

Kok, K., 2004. The role of population in understanding Honduran land use patterns. Journal of Environmental Management 72, 73–89.

Kok, K., Veldkamp, A., 2000. Using the CLUE framework to model changes in land use on multiple scales. In: Bouman, B.A.M., et al. (Eds.), Tools for land use analysis on different scales, with case studies for Costa Rica. Kluwer Academic Publishers, Dordrecht, pp. 35–63.

Kok, K., Winograd, M., 2002. Modeling land-use change for Central America, with special reference to the impact of hurricane Mitch. Ecological Modeling 149, 53–69.

Kok, K., Patel, M., (Eds.), 2003. Target Area scenarios. First sketch. MedAction Deliverable 7. Report number I03-E003, ICIS, Maastricht.

Kok, K., Rothman, D.S., 2003. Mediterranean scenarios. First Draft. MedAction Deliverable 3. Report number I03-E001, ICIS, Maastricht.

Kok, K., Rothman, D.S., Greeuw, S., Patel, M., 2003. European scenarios. From VISIONS to MedAction. MedAction Deliverable 2. Report number I03-E004, ICIS, Maastricht.

Kuhlman, T., Koomen, E., Groen, J., Bouwman, A., 2005. Simulating agricultural land use change in the Netherlands. In: Transition in Agriculture and Future Land Use Patterns. Kluwer, Dordrecht.

Lambin, E.F., Rounsevell, M.D.A., Geist, H.J., 2000. Are agricultural land-use models able to predict changes in land-use intensity?. Agriculture Ecosystems & Environment 82, 321–331.

Lambin, E.F., Turner II, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skånes, H., Steffen, W., Stone, G., Svedin, U., Veldkamp, T.A., Vogel, C., Xu, J., 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change 11, 261–269.

Laurance, W.F., Cochrane, M.A., Bergen, S., Fearnside, P.M., Delamônica, P., Barber, C., D'Angelo, S., Fernandes, T., 2001. The future of the Brazilian Amazon. Science 291, 438–439.

Leemans, R., 1999. Modeling for species and habitats: New opportunities for problem solving. Science of the Total Environment 240, 51–73.

MA (Millennium Ecosystem Assessment), 2003. Ecosystems and human well-being. A framework for assessment. Report of the Conceptual Framework Working Group of the Millennium Ecosystem Assessment. Island Press, Washington, 245 pp.

van Meijl, H., van Rheenen, T., Tabeau, A., Eickhout, B., 2005. The impact of different policy environments on land use in Europe. Agriculture Ecosystems & Environment, submitted for publication.

Nelson, G., Janetos, A., Bennet, E., 2005. Drivers of change in ecosystem condition and services. In: Carpenter, S.R. (Ed.), Scenarios Assessment of the Millennium Ecosystem Assessment.

Nepstad, D., Lefebvre, P., Da Silva, U.L., Tomasella, J., Schlesinger, P., Solorzano, L., Moutinho, P., Ray, D., Benito, J.G., 2004. Amazon drought and its implications for forest flammability and tree growth: A basin-wide analysis. Global Change Biology 10, 704–717.

de Nijs, T.C.M., De Niet, R., Crommentuijn, L., 2004. Constructing land-use maps of the Netherlands in 2030. Journal of Environmental Management 72, 35–42.

van Noordwijk, M., Poulsen, J.G., Ericksen, P.J., 2004. Quantifying off-site effects of land use change: Filters, flows and fallacies. Agriculture Ecosystems & Environment 104, 19–34.

OECD (Organization for Economic Cooperation and Development), 2001. OECD Environmental Outlook. OECD Publishing, Paris, France, 328 pp.

Otsamo, A., Goran, A., Djers, A., Hadi, T., Kuusipalo, J., Vuokko, R., 1997. Evaluation of reforestation potential of 83 tree species planted on Imperata cylindrica dominated grassland. A case study from South Kalimantan, Indonesia. New Forests 14, 127–143.

Peterson, G.D., Cumming, G.S., Carpenter, S.R., 2003. Scenario planning: A tool for conservation in an uncertain world. Conservation Biology 17, 358–366.

Pijanowski, B.C., Shellito, B., Pithadia, S., Alexandridis, K., 2002. Forecasting and assessing the impact of urban sprawl in coastal watersheds along eastern Lake Michigan. Lakes & Reservoirs: Research and Management 7, 271–285.

Raskin, P., Banuri, T., Gallopín, G., Gutman, P., Hammond, A., Kates, R., Swart, R., 2002. Great Transition: The Promise and Lure of the Times Ahead. PoleStar Series Report, No. 10. Stockholm Environment Institute – Boston, Boston, United States.

Roetter, R.P., Hoanh, C.T., Laborte, A.G., Van Keulen, H., Van Ittersum, M.K., Dreiser, C., Van Diepen, C.A., De Ridder, N., Van Laar, H.H., 2005. Integration of Systems Network (SysNet) tools for regional land use scenario analysis in Asia. Environmental Modelling & Software 20, 291–307.

Rotmans, J., Van Asselt, M.B.A., Anastasi, C., Greeuw, S.C.H., Mellors, J., Peters, S., Rothman, D.S., Rijkens-Klomp, N., 2000. Visions for a sustainable Europe. Futures 32, 809–831.

Rounsevell, M.D.A., Ewert, F., Reginster, I., Leemans, R., Carter, T.R., 2005. Future scenarios of European agricultural land use II. Projecting changes in cropland and grassland. Agriculture Ecosystems & Environment 107 (2–3), 117–135.

Rudel, T.K., Coomes, O.T., Lambin, E.F., 2005. Forest transitions: Towards a global understanding of land use change. Global Environmental Change 15, 23–31.

Silver, W., Ostertag, A., Lugo, E., 2000. The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. Restoration Ecology 8, 394–407.

Solecki, W.D., Oliveri, C., 2004. Downscaling climate change scenarios in an urban land use change model. Journal of Environmental Management 72, 105–115.

Sorrensen, C., 2004. Contributions of fire use study to land use/cover change frameworks: Understanding landscape change in agricultural frontiers. Human Ecology 32, 395–420.

Thornton, P.K., Galvin, K.A., Boone, R.B., 2003. An agro-pastoral household model for the rangelands of East Africa. Agricultural Systems 76, 601–622.

Topp, C.F.E., Mitchell, M., 2003. Forecasting the environmental and socioeconomic consequences of changes in the Common Agricultural Policy. Agricultural Systems 76, 227–252.

Toth, F.L., 1988. Policy exercises. Journal of Simulation & Games 19, 235–276.

Toth, F.L., 1995. Simulation/gaming for long-term policy problems. In: Crookall, D., Arai, K. (Eds.), Simulation/Gaming Across Disciplines and Cultures: ISAGA at a Watershed. Sage Publications, Thousand Oaks, CA, 320 pp.

UNEP (United Nations Environment Programme), 2002. Global Environment Outlook 3. Past, Present and Future Perspectives. Earthscan Publications Ltd., London, UK.

UNEP (United Nations Environment Programme), 2004. Global Environment Outlook Scenario Framework. Background Paper for UNEP's Third Global Environment Outlook Report (GEO-3). UNEP, Nairobi, Kenya.

USGCSP, 2003. Strategic Plan for the U.S. Climate Change Science Program. Report by the Climate Change Science Program and the Subcommittee on Global Change Research. USCCSP, Washington.

Verburg, P.H., De Koning, G.H.J., Kok, K., Veldkamp, A., Bouma, J., 1999. A spatial allocation procedure for modeling the pattern of land use change based upon actual land use. Ecological Modeling 116, 45–61.

Verburg, P.H., Overmars, K.P., Witte, N., 2004. Accessibility and land use patterns at the forest fringe in the Northeastern part of the Philippines. Geographical Journal 170, 238–255.

White, R., Straatman, B., Engelen, G., 2004. Planning scenario visualization and assessment: A cellular automata based integrated spatial Decision Support System. In: Goodchild, M.F., Janelle, D. (Eds.), Spatially Integrated Social Science. Oxford University Press, New York, pp. 420–442.

WRR (Wetenschappelijke Raad voor het Regeringsbeleid), 1992. Ground for Choices: Four perspectives for the rural areas in the European Community. Sdu Uitgevers, The Hague, The Netherlands.

Zanne, A.E., Chapman, C.A., 2001. Expediting reforestation in tropical grasslands: Distance and isolation from seed sources in plantations. Ecological Applications 11, 1610–1621.