CLIMATE CHANGE AND LAND USE CHANGE

Department of Agroenvironmental Science and Technologies (DiSTA) - University of Bologna (UNIBO)
Author: Andrea Monti (a.monti@unibo.it)

Preface

Interactions between climate change and land use are very intricate and not well understood as they depend on decisions at different scale levels, from farmers to global organisations, as well as on the choice of model driver parameters: technological and demographic developments, food and feed demands, social and economic opportunities, land use and crops competitions, environmental challenges, protected areas etc.. Furthermore, when the assessment of land use is restricted to European lands, it is important to take into account how this can be influenced by global trade outside of Europe. That is, land use will depend not only by the internal demand/supply, but also by products imported from non-European countries. To obviate this, global trade simulating models should be used.

A further difficulty in the analysis of climate change - land use/cover relationships is that climate change generally causes counteracting and/or feedback effects on crop productivity and thus in turn on land use. The rise in atmospheric CO_2 concentration, for example, may increase the crop yield, especially in C_3 crops, but at the same time, it will lead to higher greenhouse effects and water shortage, especially in southern Europe, which in turn will negatively affect the crop productivity. Whether and to what extent the rise in CO_2 will offset the more severe drought conditions is still a controversial matter. A recent study reported that the average crop yield across Europe will change from -3% to +1% due to climate change, from +11% to 32% due to the increase in atmospheric CO_2, from +25% to +136% due to the advances in technology (Ewert et al., 2006; Rousenvell et al., 2005; 2006). Though these findings greatly changed in relation with specific environmental conditions, the authors estimated that, depending on orientation towards sustainable agricultural systems, from 50% to 67% less land will be used for crop production over the next 50-70 years.

Nonetheless, the reduction of conventional crop lands does not imply that agricultural lands will decline as well; rather, it may provide new challenges for non-conventional agricultural land uses such as biofuels, forestry, fibre or industrial crops in general, recreational areas etc.. In this regard, it should be reminded that about 19 Mha grown with energy crops would be needed to fit the European targets at 2020 on bioenergy, an amount which is close to the estimated available lands by European Commission for biomass crops at 2020 (18 Mha) and 2030 (20 Mha), respectively (Wiegmann et al., 2005). For biofuels only, it was estimated that between 4% and 13% of the total agricultural land in the EU25 would be needed to produce the amount required to reach the level of liquid fossil fuel replacement as specified in the Directive 2003/30/EC. Outstanding benefits could derive from these opportunities of land use in term of economic and social consequences or environment and climate mitigation, yet they are largely unknown.

Despite considerable progress in modelling land use (Veldkamp and Verburg, 2004), prediction of future land use/cover remains very uncertain. Nonetheless, scientists must somehow provide reliable supporting tools to policy makers, and to accomplish this they generally use simulation models of different complex levels by which they can explore land use changes and trade-offs within scenarios according to the "what-if" concept (Veldkamp and Lambin, 2001; Veldkamp and Verburg, 2004). Though the objective of this section is not to present model outlines (see Briassoulis, 2000 and Veldkamp and Lambin, 2001 for extent reviews), some point should be reminded yet. First, nearly all models assume that land use change is driven by both socio-economic and biophysical forces. Second, the latter does not affect land use change directly but it can lead to land cover and crop yield variations through a change of climate factors.

A look back

Agriculture and forestry are the most relevant land uses in Europe covering about 45% and 36% of the total land area, respectively (FAO, 2008). In the last 40 years the agricultural land has decreased by about 15% in front of an increase by 20% in population and food demand (FAO, 2008). Therefore, a decreasing agricultural land had to offset a growing demand for food. This was possible thanks to the advances in agricultural technologies and breeding programs that allowed a huge increase in crop productivity, up to about 150% in cereals. As a consequence, during the last decades production overall exceeded demand thus resulting in considerable oversupply. Nonetheless, while crop lands have declined, forest lands have considerably grown thus to counterbalance the contraction in agricultural lands, though these two opposite trends were not directly related (Kankaanpää and Carter, 2004).

A look forward

Intergovernmental Panel on Climate Change (IPCC) provided amassing evidence that increase in atmospheric GHG concentrations leads to a rise of temperature while altering the patterns of rainfall and climate factors for a large part of Europe (Fig. 1, 2). There is a wide consensus that this will occur rapidly and accompanying land use change shall be expected accordingly. However, the influence of climate change upon land use is not unequivocal: there is a still high uncertainty in land use model predictions (Pontius and Malanson, 2005) as several recent studies produced very different scenarios (Brower and McCarl, 2006).

These contrasting results can be explained by the intricate relationships between factors. For example, food and feed demands are projected to increase rapidly, and these will likely affect land use to an even more extent than climate change thus making the projections on land use further unclear. Climate change will in turn affect the productivity of crops (Ewert *et al.*, 2005), which influences the agricultural land use (Rounsenvell et al., 2005), and this, again, will affect climate change thereafter through the emission and sequestration of GHG from soil and productive processes. Recent studies using the fully coupled Department of Energy Parallel Climate Model (DOE-PCM) (Meehl *et al.*, 2005) to simulate combined land cover and atmospheric forcings have in fact shown that future land use, and land cover, will be important drivers of climate change. Nonetheless, the role of land use and land cover change in altering regional temperatures, precipitation, vegetation, and other climate variables has been mostly ignored. As a result, IPCC (Intergovernmental Panel on Climate Change) simulations on climate change can be expected to be significantly worse from those based only on air composition change (Feddema *et al.*, 2005; Pielke, 2005).

For example, Feddema *et al.* (2005) reported that even minor deforestation can alter local rainfall patterns and the conversion of forests to agriculture will probably lead to a significant warming well above the predicted 2°C. Again, Guo and Gifford (2002) reported that soil carbon stocks increased by 18% after land use changes from crop to grasslands, while it decreased up to 59% when pasture was converted in cropland. These results were also corroborated by more recent studies proving substantially different environmental impacts of perennial and annual crop systems (Fargione et al. 2008). That land use and land cover will act as major drivers of climate patterns should not surprise as NASA reports that "between one-third and one-half of our planet's land surfaces have been transformed by human development". Therefore, a not clear hierarchical relationship seems to be between climate change and land use, indeed a sort of "Catch 22" (Heller, 1961) mutual influence between them likely exists.

Projections of land use

We refer to a number of recently published studies on land use scenarios undertaken within the framework of the European Union funded research Projects ATEAM and ACCELERATES (Rounsevell et al., 2005; Ewert F. et al. 2005; Tuck et al., 2006; Rounsevell et al., 2006). These studies assumed the following hierarchical competition on land use: protected areas > urban > cropland > grassland > bioenergy crops > commercial forest > non actively managed lands (or surplus lands mostly represented by abandoned lands). Briefly, urban land is geographically limited by housing demand and by land use planning policies. Bioenergy crops rank below food production, the latter being reasonably assumed to take precedence over energy demand. In addition, the proximity to urban centres for efficient heat use was taken into account for a coherent allocation of bioenergy crops. An assumption was made that European protected areas will progressively increase up to 20% by 2080. The hierarchy is also adjusted according to productivity differences with latitude and crops. For example, in northern latitudes, forests prevail over agriculture because in these areas agricultural productivity is too low.

The methodology was based on different marker storylines of the IPCC of Special Report on Emission Scenarios (SRES) (Nakicenovic et al.,2000) integrated with climate change scenarios derived from HadCM3 model (Mitchell et al., 2004). Each SRES storyline describes different situations in term of socio-economic, demographic, technological and environmental conditions. The influence of global market demands outside Europe was taken into account by the use of IMAGE model which predicts global demands for animal products, food crops, grass and fodder species, wood and biofuel crops.

The effect of climate change (not including CO_2) was calculated from the change in yields between the baseline and each future climate scenario. Average crop yield in each grid cell was estimated by an empirical model based on the Environmental stratification of Europe (EnS) as given by Metzger et al. (2005). Breifly, each yield value (Eurostat, 2000) was associated to the relative stratification class through the intersection of the geographical location of each class with crop yield. Changes in crop yield were modeled accounting for effects of climate change, CO_2 increase and technology development assuming that these effects were additive. The effects of increasing atmospheric CO_2 concentrations were calculated by the relative yield change per unit increase in CO_2 and the difference between the today and future CO_2 concentration (Amthor, 1998). The latter was estimated to be from 417 to 427 μmol mol^{-1} in 2020 (best and worse scenario, respectively) and from 518 to 766 μmol mol^{-1} in 2080 (HadCM3 model). The relative yield change per unit CO_2 concentration was set to 0.08%. The effects of climate change on crop yield were calculated from the strong correlation between crop yield at regional level (Eurostat, 2000) and environmental strata (Metzger et al., 2005). Changes in climatic conditions generated by HadCM3 model (Mitchell et al., 2004) were used to calculate changes in the distribution of environmental strata and thus in turn of changes in the distribution of crop yields (Fig. 3).

Overall, the results show that the increases in crop productivity in 2020 will be from 25% to 41% (from 43 to 163% in 2080), mostly due to technological development and to a lesser extent to CO_2 increase (about 4% in 2020; from 12% to 32% in 2080, depending on scenario) and climate change (about 1%, irrespective of time scale). Climate change and increasing CO_2 concentration increase crop yields compared to the baseline in north Europe while decreasing yields in southern Europe, especially in Spain, Portugal and south Italy and secondary in France and north Italy (Fig. 3). Negligible effects of climate change will occur in the rest of Europe. Due to technological development a large reductions in land use for food and feed production was estimated, which were partially offset by forest land, protected areas and energy crops lands (Fig. 4). Variations in urban areas are conversely negligible. In the two last scenarios of Fig. 4 the abandoned lands (surplus) are strongly reduced as it is assumed that the policy towards limiting crop productivity are adopted to cope with land abandonment. Measures could be the promotion of extensive cropping systems, organic farming and the replacement of food crops with energy crops. Importantly, in all scenarios crop land declines mostly due to the technology development. However, how this interacts with land use and climate change relationships is not understood and therefore should be considered more explicitly in future researches.

European Commission has planned to strongly increase the investment on bioenergy crops in short term as important renewable alternatives to replace fossil fuels. Therefore, reliable land use change scenarios should always include these crops along with the traditional ones. In this regard, a recent study (Tuck et al., 2006) have derived maps of the potential future distribution of 26 energy crops (oil, starch and solid biofuel crops) in Europe, based on crop adaptability and tolerance to the climatic conditions as predicted by SRES emission scenarios (IPCC). A limit of this study was that potential crops distribution was estimated on the base of growth temperature and rainfall, while soil type, slope yield and markets were not take into account. Overall, the results show that the possibilities to successfully grow oilseeds, cereals, starch crops, and solid biofuels are expected to increase in north Europe, mostly due to higher summer temperatures, and decrease in southern Europe (e.g. Spain, Portugal, southern France, Italy, and Greece) due to water shortage. These trend is initially slightly visible (2020) and then it becomes much more pronounced (2080 scenarios) according to other global climate models (e.g. CSIRO2, PCM and CGCM). Spain appears particularly affected by climate change, which causes a drastic decline of many temperate crops in this area. Therefore, there is evidence that the choice of bioenergy crops in southern Europe will be restricted to a very small number of crops (e.g. sorghum, sunflower and miscanthus) unless alternative agronomy strategies (e.g. earlier sowing) or selection programs will provide new genotypes with higher drought adaptability. However, it should be underlined that other solid biofuels were not included in this analysis which can be expected to be more tolerant than miscanthus to drought (e.g. giant reed and switchgrass).

REFERENCES

1. Amthor J.S. **1998**. Field Crops Res. 58, 109-127.
2. Briassoulis H. **2000.** In: S. Loveridge (ed), The web book of Regional Science. www.rri.wvu..edu/regscweb.htm
3. Brower F., McCarl B.A., **2006.** In: Brower F., McCarl (Eds): Agriculture and Climate beyond 2015. *Springer*, NL, 1-4.
4. Ewert F. et al. **2005**. *Agric. Ecosyst. Environ*. 107, 101-116.
5. FAO 2008. Internet database. http://www.fao.org
6. Fargione et al., **2008**. *Science* 319, 1235 - 1238
7. Feddema, J.J. et al. **2005**. *Science* 310, 1674-1678.
8. Guo L.B., Gifford R.M. **2002**. *Global Change Biol.* 8, 345-360
9. Heller J. **1961**. Catch-22. Simon and Schuster, New York.
10. Kankaanpää S., Carter T.R. **2004.** In: The Finnish Environment 706, Finnish Environment Institute, Helsinki.
11. Meehl G. A. et al. **2005**. *Science* 307, 1769.
12. Metzger M.J. et al., **2005**. *Global Ecol. & Biogeog*. 14, 549-563.
13. Mitchell et al., **2004.** Working Paper, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich.
14. Nakicenovic N., et al. **2000**. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge.
15. NASA Earth Observatory news feature (http://earthobservatory.nasa.gov/Study/DeepFreeze/deep_freeze5.html).
16. Pielke Sr. R.A. **2005**. *Science* 310, 1625-1626.
17. Pontius R.G., Malanson J. **2005**. *Int. J. Geog. Inf. Sci*. 19, 243-266.
18. Rounsenvell et al., **2005**. *Agric. Ecosyst. Environ*. 107, 117-135.
19. Rounsenvell et al., **2006**. *Agric. Ecosyst. Environ*. 114, 57-68.
20. Tuck G., et al. **2006**. *Biomass Bioenerg*. 30, 183-197.
21. Veldkamp A., Lambin, E.F. **2001**. *Agric. Ecosyst. Environ*. 85, 1-6.
22. Veldkamp A., Verburg P.H. **2004.** *J. Environ. Manage.* 72, 1–3.
23. Wiegmann K., Fritsche U., Elbersen B. **2005**. Consultancy EEA Report.

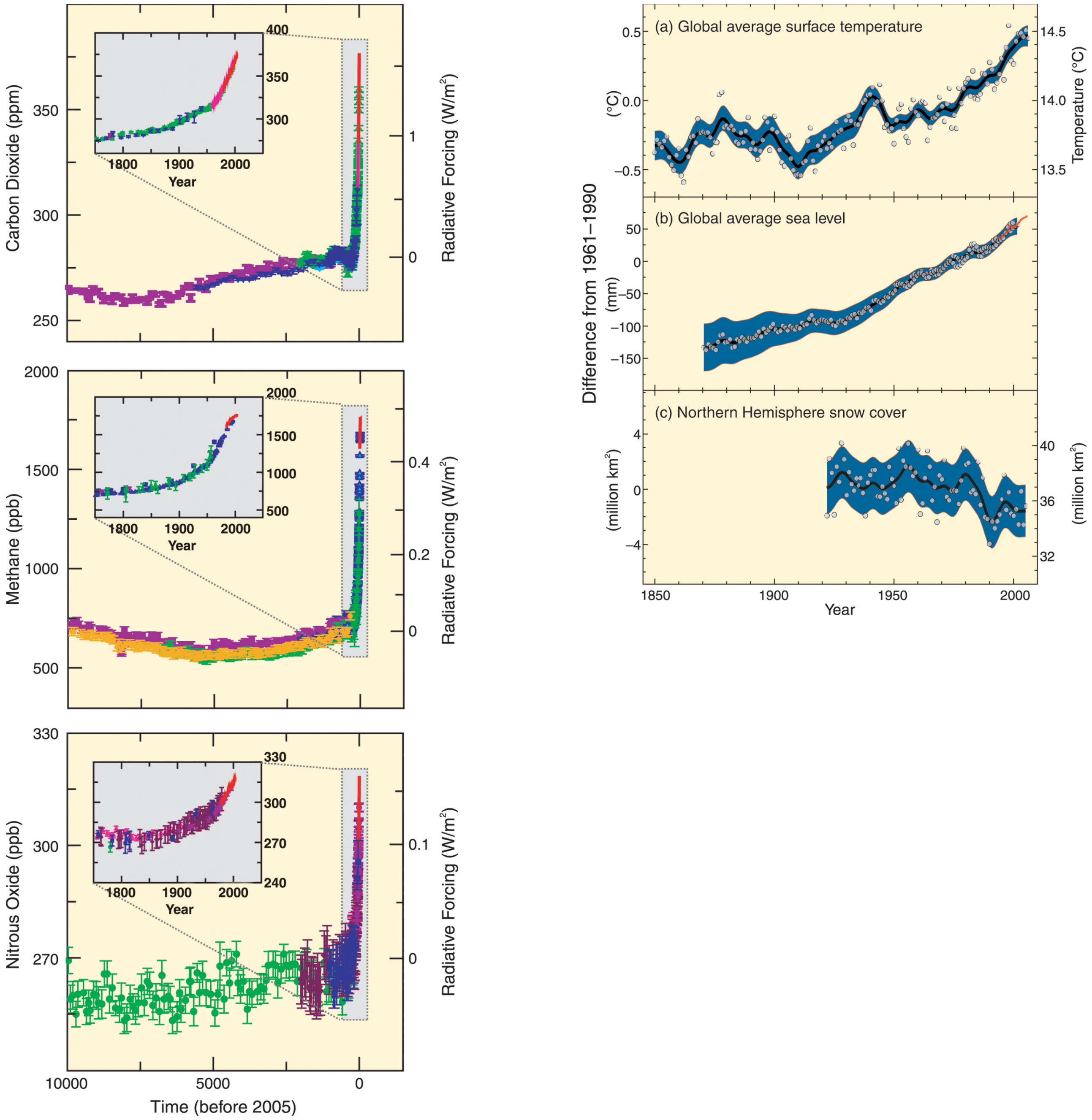

Fig. 1. Hockey stick patterns of CO_2, methane and nitrous oxide (right) and their consequences on air temperature, sea level and snow cover (IPCC, 2007).

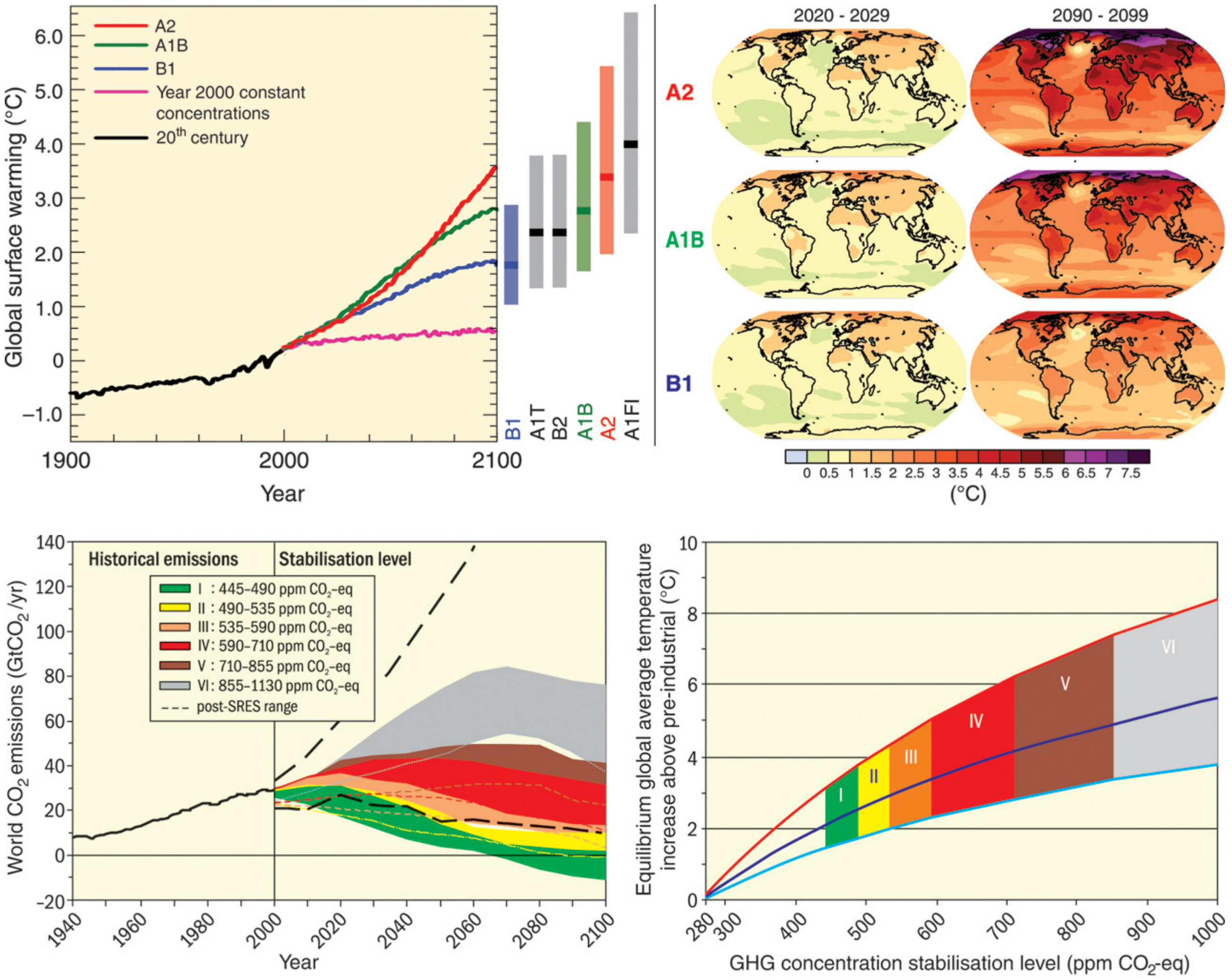

Fig. 2. Projections of global warming and CO_2 emissions according to different scenarios (IPCC, 2007).

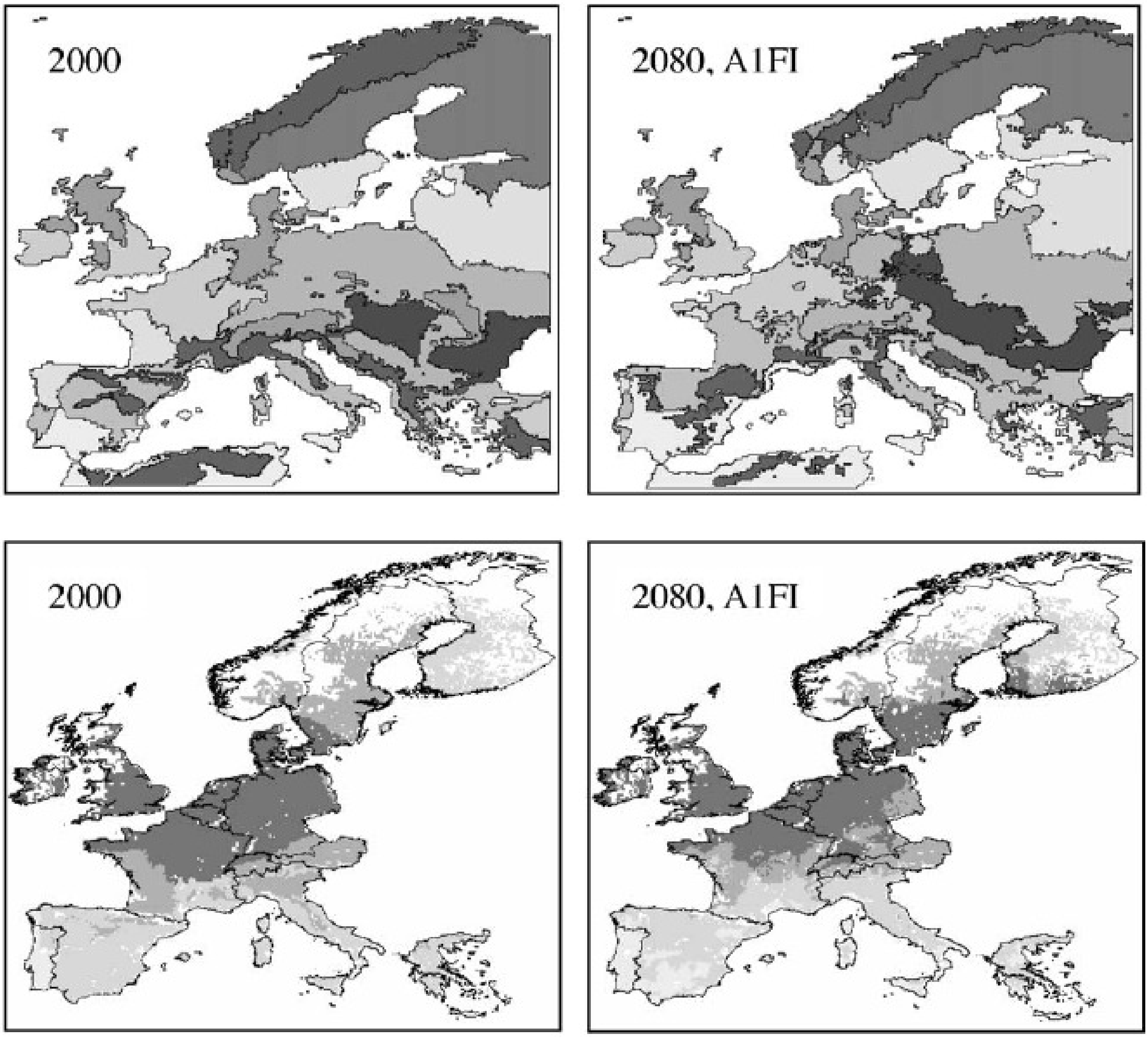

Fig. 3. Distribution of environmental zones (top figures) and wheat yields (bottom figures) in 2000 and 2080. Same colors indicate same environmental zones or yield levels, the latter increasing from white to black.

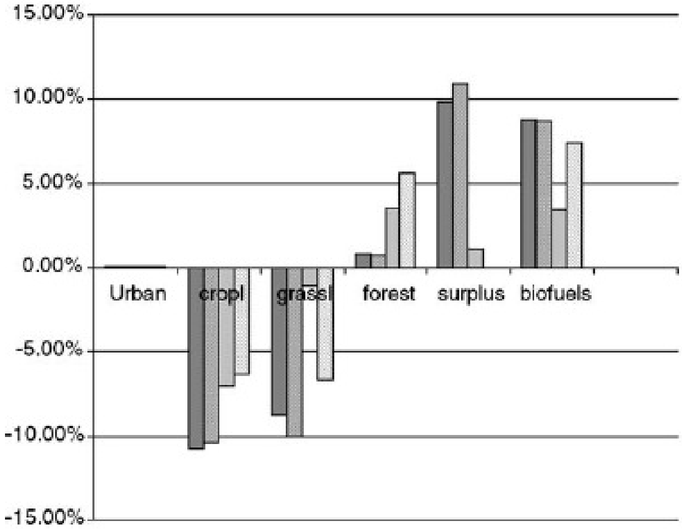

Fig. 4. Projections of competitive land uses. Bars indicate four different scenarios according to SRES scenarios elaborated by IPCC (source: Rounsenvell et al., 2006). Surplus land indicate "non actively managed lands" mostly represented by abandoned agricultural lands.