Linking global trends to local impacts in spatially explicit integrated assessments
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2. Future land use patterns in European catchments: scenario trends in urbanization, agriculture and land use
Abstract

Land use in the European Union is expected to change significantly during the next decades, which may have important hydrological impacts. Land use change was modelled in ten different European river basins using the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). Model results predict some overall scenario trends comparable in most basins. The ‘(A1) Global Economy’ and ‘(B1) Global Cooperation’ scenarios predict a large increase in urban area plus abandonment of agricultural land. The ‘(A2) Continental Markets’ scenario predicts an increase both in urban area and in agricultural land. The ‘(B2) Regional Communities’ scenario predicts a relatively small increase in urban area and modest land abandonment. Overall trends can also be discerned for each land use type. Urban area increases in all scenarios and all river basins. Agricultural land use decreases in all scenarios due to urbanization and land abandonment, except in the ‘Continental Markets’ scenario. Natural vegetation and abandoned land increase in most scenarios as a result of the projected abandonment of agricultural land, except in the ‘Continental Markets’ scenario. There are also differences between individual river basins. The Loire, Seine and Tevere basins show a change from agricultural land towards abandonment and natural vegetation, but magnitude and direction of this change differ between scenarios. The same is predicted, but to a lesser extent, in the Ebro, Elbe, Kokemäenjoki and Tago basins. Land use in the Oder basin remains relatively stable except that some pasture is abandoned in the ‘Regional Communities’ scenario. The Thames basin consistently shows high levels of urbanization in all scenarios, whereas land use change in the equally urbanized Scheldt basin varies considerably between the scenarios and is rather unpredictable. In general, the distribution of land use within river basins does change—but not dramatically—over the modelled time horizon of 30 years. The magnitude of changes in land use predicted in this study will not likely cause large-scale impacts on the hydrological characteristics of entire river basins, except for the sediment load of the river. Nonetheless, they may cause important local impacts, i.e. at the level of small catchments and subcatchments such as increased occurrence of low flows, drying up of streams and flash floods.

2.1 Introduction

The EU’s rural area is expected to undergo profound changes in land use during the next decades. On-going agricultural intensification and mechanization are thought to lead to a contraction of Europe’s agricultural area and depopulation of rural areas with marginal yields (Rabbinge and Van Latsteijn, 1992; Busch, 2006; Verburg et al., 2006; Rounsevell et al., 2005). Although it is not yet clear how these abandoned land areas will develop, substantial parts will probably become occupied with natural vegetation such as forest (Rounsevell et al., 2005; Verburg and Overmars, 2009). Urbanization is another important process in many rural areas that significantly changes the traditional landscape and land use characteristics in these areas (Verburg et al., 2006; Antrop, 2004).

These land use changes can have a great impact on the hydrological characteristics of a catchment. Natural vegetation (such as forest) tends to have a considerable retention capacity by retaining water during heavy precipitation and slowly releasing it afterwards (Bradshaw et al., 2007; Laurance, 2007). In addition, natural vegetation tends to have high transpiration and evaporation rates compared to cropland and to improve the infiltration capacity of the soil. This means that a decrease in natural vegetation (i.e. deforestation) in a catchment will result in larger and more unpredictable (peak) discharges (Bradshaw et al., 2007; Laurance, 2007; Petts and Foster, 1985; Hurkmans et al., 2009), whereas an increase in natural vegetation or reafforestation can result in the opposite (Fohrer et al., 2001). Especially urbanization can have negative hydrological effects due to the very low infiltration capacity of its paved areas (Hurkmans et al., 2009).

Because land cover changes are known to have a great impact on hydrological processes, more insight into the future development of EU’s rural area will help understanding what potential changes in hydrological processes can be expected. Several studies have addressed the effects of rural land use changes within the EU on hydrological processes (Hurkmans et al., 2009; Niehoff et al., 2007; Bronstert et al., 2007; Ward et al., 2008), but many of these studies have described land use changes at the local catchment scale and not at multiple catchments simultaneously. This makes it difficult to compare changes in land use between different catchments and discern main trends from local changes. Therefore, the aim of this study is to determine land use changes in a range of European catchments and to compare trends in land use change among catchments based on land use change scenarios derived from a previous study (WUR/MNP, 2008). Scenarios based on the well-known IPCC/SRES scenarios describing different societal development
directions are used to derive assumptions regarding key drivers of land use change. Using these assumptions, the scenarios are translated with the EUruralis model ensemble into local land use changes at a spatial grid of 1 km² over the period 2000-2030. Changes in land use are then analyzed and compared in different European catchments.

2.2 Methodology

**Outline**
The data used in this study have been developed within the EUruralis project (WUR/MNP, 2008). The EUruralis project grasped the potential development directions of the rural area in the EU25 using the IPCC/SRES scenarios (Lorenzoni et al., 2000; Westhoek et al., 2006; Vermaat et al., in press). The EUruralis consortium used its own interpretation of these scenarios and named them differently (where A1 = Global Economy, A2 = Continental Markets, B1 = Global Cooperation and B2 = Regional Communities; see Busch, 2006). Assumptions regarding key drivers of land use change (e.g. macroeconomic and demographic developments) were derived from the scenario-interpretations (Westhoek et al., 2006). Based on these key drivers, a macro-economic model (Global Trade Analysis Project: GTAP) and an integrated assessment model (Integrated Model to Assess the Global Environment: IMAGE) are used to calculate agricultural land use changes per EU country over the period 2000-2030 (Van Meijl et al., 2006). The aggregated land use changes calculated by GTAP/IMAGE have been translated into local changes at a spatial resolution of 1 km² with a land use change model (Dyna-CLUE; Verburg and Overmars, 2009).

**Models**
GTAP is a macro economic model that calculates international trade between world regions using input-export tables for each world region (Van Meijl et al. 2006). Production systems within each region are modelled through input-output tables, in which the whole production chain is included. At each step in the production chain, the most profitable use of resources is determined. The consequences for the production chain and other economic sectors are determined. Scenario assumptions regarding key drivers of land use (e.g. macroeconomic and demographic developments) have been considered as preconditions within the model. In this structure, agricultural production was included as a production chain with some adjustments to account for the fact that land use types are not perfectly interchangeable and that there is a limited land supply (Verburg et al., 2008).
The integrated assessment model IMAGE is used to adjust the calculations of GTAP regarding agricultural production by taking into account the effects of climate change and land use change (Eickhout et al., 2007). It calculates the effects of climate change and of the land use changes calculated by GTAP on the agricultural yields used in GTAP’s calculations. The modified yields are returned to GTAP, which renews its calculations with the modified yields. The looping between GTAP and IMAGE continues until the models converge. The resulting output simulates the production and trade of goods and services between different world regions, and includes the land area dedicated to arable and livestock production per EU country.

Spatial land use changes are simulated by Dyna-CLUE using competition among land use types (Verburg et al., 2006). This competition is based on the comparative suitability of a location for the various land use types. The comparative suitability of a location for the various land use types is based on local biophysical and socioeconomic factors. At each location the model allocates a land use type with the highest suitability, and then compares the allocated changes in land use with the aggregated national land use changes that have been calculated by GTAP/IMAGE. If the models do not converge, Dyna-CLUE adjusts the comparative suitability of the under- and over-allocated land use types until the models do converge. In this way, Dyna-CLUE translates the aggregated national land use changes calculated by GTAP/IMAGE into local land use changes at a spatial resolution of 1 km² (Verburg et al., 2006). Time steps of 1 year are used and a total period of 30 years is modelled (i.e. 2000-2030). Dyna-CLUE actively models competition between six land use types, and an additional eight land use types are included that are not dynamic (e.g. bare rock, glaciers, etc.). Additionally, two land use types are used to model land abandonment (i.e. recently abandoned arable land and recently abandoned pasture). Land abandonment is not actively modelled in Dyna-CLUE, but is allocated to locations that are literally ‘left-over’ after sufficient area has been allocated to other land use types to meet the area requirements calculated by GTAP/IMAGE. After a set time period, abandoned land is assumed to have developed a full natural vegetation cover and changes automatically into first the land use type ‘natural vegetation’ and later into forest depending on the local conditions for forest regrowth. Land use types ‘abandoned land’ and ‘natural vegetation’ are thus coupled.

**Analysis**

EUruralis scenario outputs of 2030 are compared with the land use map of the initial year to determine which land use changes have occurred in different catchments in each scenario. Land use changes have been determined in ten catchments; those of the Ebro, Elbe, Kokemäenjoki, Loire, Oder, Scheldt, Seine, Tago,
Thames and Tevere (figure 2.1). These catchments were chosen because (1) they show a reasonable geographical spread, (2) most are relatively large or (economically) important rivers, and (3) EURuralis outputs cover the entire catchment area. The latter is not true for the Rhine and Danube, hence these important catchments are not included. The various land use types modelled within the EURuralis project have been aggregated into five broad land use categories in this study: urban area, natural vegetation, abandoned land, pasture and arable land.

Figure 2.1 Catchments included in the analysis, with the EU25 as background.

2.3 Results and discussion

Scenarios
In general, the largest parts of the selected catchments remain under the same land use types, but locally considerable landscape changes can sometimes be observed. While land use changes within a scenario can differ between catchments, some overall scenario trends can still be identified after pooling land use changes across catchments per scenario (figure 2.2). The main changes in the ‘Global economy’ scenario are a large increase in urban area (the largest increase in urban area of all scenarios) and a large decrease in arable land (but not of pasture) resulting in a
substantial increase in natural vegetation and abandoned land. This high urbanization rate is probably due to the scenario’s limited government regulation, strong population growth (including immigration) and relatively high levels of affluence. This would result in a large, wealthy urban population that requires a lot of area per person and because this high demand for space per person is not balanced by government restrictions, high urbanization rates are the result. The decline in agriculture is probably coupled to the termination of the EU’s agricultural subsidies and reduction of import tariffs in the ‘Global economy’ scenario.

In the ‘Global cooperation’ scenario, land use changes are comparable to those of the ‘Global economy’ scenario. Urbanization rate is somewhat lower and agricultural land abandonment (of both arable land and pasture) is higher. This results in a large increase in natural vegetation and abandoned land. EU agricultural subsidies and border/domestic support (import tariffs) are phased out as well, which explains the substantial abandonment of agricultural land.

The ‘Continental markets’ scenario shows urbanization rates that are comparable to the previous two scenarios. This is somewhat surprising given the lower population growth and affluence level compared to the ‘Global economy’ and ‘Global cooperation’ scenarios. A probable explanation can be the absence of restrictive spatial planning regulation. In contrast with the other scenarios, the area of agricultural land remains relatively stable or even increases in some catchments. This expansion of agricultural land occurs at the expense of natural vegetation and consequently results in a decrease of natural vegetation and a very small increase in abandoned land in this scenario. Agricultural policy aimed at stimulating production through export subsidies and import barriers is probably the reason for the strong agricultural growth.

The ‘Regional communities’ scenario shows relatively low levels of urbanization, which is consistent with the assumptions of low population and economic growth plus governmental regulations on urban sprawl. This scenario also projects a relatively small decrease in agricultural land, and a corresponding modest increase in natural vegetation and abandoned land, which can be attributed to the desire for local self-reliance and associated support for local agricultural production.

**Land use**

Overall trends can also be discerned for each land use type (figure 2.2). Urban area is projected to increase in all scenarios and all catchments, but the increase is especially pronounced in the ‘Global economy’ scenario. Urbanization is much lower
Figure 2.2 Variation in projected land use changes that exists among the different catchments within each scenario. Shown is the median and full range of the land coverage of each land use type among all catchment per scenario (given as a percentage of the area of that specific land use type in the base year). In the case of abandoned land, the area abandoned land in each scenario is expressed as a percentage of the combined area of arable land and pasture in the start year because the area abandoned land in the start year is not known.
in the ‘Regional communities’ scenario and intermediate in the ‘Continental markets’ and ‘Global cooperation’ scenarios. This is in line with the scenario assumptions: the ‘Global economy’ scenario assumes the highest increase in population and economic growth, and ‘Regional communities’ the lowest. The difference in variation among catchments is notable (i.e. larger range in figure 2.2) between the ‘Global economy’ and ‘Continental markets’ vs. ‘Global cooperation’ and ‘Regional communities’ scenarios. The differences in urbanization among catchments are clearly much larger in the former than in the latter two. Urbanization appears an especially important land use change process in the catchments of the Thames, Seine, Tago and Loire.

The two agricultural land use types (arable land and pasture) show a more complicated trend. Arable land decreases in most scenarios, except for the ‘Continental markets’ scenario where in some catchments a reasonable increase in arable land can be observed. Despite the overall decrease in arable land, considerable differences exists among catchments and some catchments even show a small increase in arable land in some scenarios. Pasture generally decreases in all scenarios, but considerable differences exist among catchments and among scenarios (with some catchments actually displaying a small increase in pasture in one or more of the scenarios). Unlike with arable land, the large decreases in pasture are seen in different catchments in the scenarios.

Natural vegetation is expected to generally increase a bit in the ‘Global cooperation’, ‘Regional communities’, and ‘Global economy’ scenarios but to decrease in the ‘Continental markets’ scenario. For the Thames large decreases in natural vegetation have been estimated in all scenarios. Abandoned land increases substantially in all scenarios except for the ‘Continental markets’ scenario. Land abandonment occurs in almost all catchments and under all scenarios.

**Catchments**

Depending on the scenario, the catchments of the Loire, Seine and Tevere show either a transition from agricultural land (arable land and pasture) to abandoned land and natural vegetation or vice versa (figure 2.3 and figure 2.4). Still, in most scenarios agricultural land is abandoned and the land use types abandoned land and natural vegetation increase substantially. Only in the ‘Continental markets’ scenario the opposite process can be seen, as the area agricultural land is projected to expand at the expense of natural vegetation. The same interaction between agricultural land vs. abandonment and natural vegetation can be seen in the Ebro, Elbe, Kokemäenjoki and Tago though less extensive. Land use in the catchment of
Figure 2.3 Absolute land coverage (in 1000 ha) of the different EURuralis land use types in 2030 per catchment that are projected according to each of the four scenarios. Land coverage is also shown for the base year 2000. GE: Global economy (A1), CM: Continental markets (A2), GC: Global cooperation (B1), RC: Regional communities (B2).
Figure 2.4 Proportional land use projections of EUruralis per catchment in 2030 according to the four scenarios compared to the base year 2000 (given as a percentage of the catchment’s area). Further as figure 2.3.
the Oder remains relatively stable except that some pasture is abandoned in the ‘Regional communities’ scenario.

In the catchment of the Thames, on-going urbanization makes that natural vegetation disappears and the urban area increases in all scenarios. The urbanization rate is especially high in the ‘Global economy’ scenario, which is not surprising as population growth and economic progress are highest in this scenario.

Initially, the catchment of the Scheldt is equally urbanized as the Thames, but it shows different land use changes and experiences lower urbanization rates in all scenarios. In the ‘Global cooperation’ and ‘Regional communities’ scenarios, a small increase in urban area and natural vegetation is observed in the catchment of the Scheldt at the expense of arable land. In the ‘Continental markets’ scenario, an increase in urban area and arable land is observed in the Scheldt’s catchment at the expense of natural vegetation. A high urbanization rate occurs at the expense of arable land and natural vegetation in the ‘Global economy’ scenario.

**Impacts on hydrology**

Large scale changes in land use are likely to have a significant impact on discharge and high flow frequencies (Petts and Foster, 1985; for an example on the deforestation of the Meuse catchment, cf. Ward, 2009). However, modest changes in land use have a minor effect on discharge distribution. Tu (2006) showed that historical land use changes in the Meuse catchment over the 20\textsuperscript{th} century have had a marginal impact on the discharge. Similarly, Ward (2009) showed for the Meuse that projected changes in discharge for the 21\textsuperscript{st} century can mainly be attributed to climatic changes, and not to changes in land use. Modest changes in land use do, however, have a great impact on sediment yield (Ward, 2009), both on local and entire catchment scale, affecting river morphology, erosion and sedimentation.

While land use changes as modeled in this study are not likely to have large effects on the discharge distribution of reasonably sized catchments, they can have a considerable impact at the local scale (i.e. small catchments or sub-catchments). For instance, De Moor (2006) found that historically local land use changes have had a considerable influence on the hydrology of a subcatchment of the Meuse (i.e. Geul). Likewise, Keesstra (2006) showed that natural reforestation (going from 30\% to 70\% during 1954-1985) greatly impacted the hydrology of a small Slovenian catchment (i.e. Dragonja). Discharge dropped dramatically, with especially low flows decreasing by about 85\%, resulting in a much more frequent drying up of the stream. Hence at local scales, especially far upstream in catchments or in very
small catchments in general, land use changes as modeled for the river basins under investigation can have substantial effects on river hydrology and sediment yield. Catchments with a relative large projected increase in natural vegetation, like the Tevere (up to 58% of the catchment’s area in B2), may respond with a reduced base flow because of the increased potential evapotranspiration of forest compared to arable land and pasture. This can be exacerbated because of climate change. Catchments with a large projected increase in urban area, like the Thames, Seine, Tago and Loire, will probably witness more frequent flooding events after extreme rainfall due to the reduced infiltration capacity and increased surface runoff of paved urban areas.

2.4 Concluding remarks

In general dramatic land use changes have not been projected to occur over the period 2000-2030, although locally considerable landscape changes can sometimes be observed. Per catchment, relative land use changes can be very different among scenarios, but often remain small in actual area. Per scenario, land use changes differ among European catchments: some urbanize greatly, where for others land abandonment is projected.

Urban land use is expected to increase in all European catchments under all scenarios. In many catchments we observed a transition either from agricultural land use (arable land and pasture) to nature and abandoned land or vice versa, depending on the scenario. In most cases agricultural land uses decreased in favour of nature and abandoned land, except under the ‘Continental markets’ scenario where agricultural land use even increases slightly in many catchments at the expense of nature.

The projected land use changes in this study are expected to have unsubstantial effects on the hydrology of the entire river basin. However, they are large enough to have an impact on sediment loads both on local and entire river basin level. The projected land use changes can be substantial in subcatchments that are subject to considerable land use change. Notably, further urbanization in Thames and Scheldt basins will lead to increased incidence and volume of peak flows, and a larger area of natural vegetation (as a result of land abandonment) may reduce base flow in Mediterranean catchments like the Tevere.
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