Global Environmental Change 40 (2016) 101–111

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Demand for biodiversity protection and carbon storage as drivers of global land change scenarios

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ARTICLE INFO

Article history:
Received 26 September 2015
Received in revised form 23 June 2016
Accepted 27 June 2016
Available online 2 August 2016

Keywords:
Agricultural intensification
Land use and land cover
Land-change model
Biodiversity
Terrestrial carbon
Ecosystem services

ABSTRACT

Many global land change scenarios are driven by demand for food, feed, fiber, and fuel. However, novel demands for other ecosystem services give rise to nexus issues and can lead to different land system changes. In this paper we explore the effects of including multiple different demands in land change scenarios. Our reference scenario is driven by demands for crop production, ruminant livestock production, and provisioning of built-up area. We then compare two alternative scenarios with additional demands for terrestrial carbon storage and biodiversity protection, respectively. These scenarios represent possible implementations of globally agreed policy targets. The simulated land system change scenarios are compared in terms of changes in cropland intensity and area, as well as tree and grassland area changes. We find that the carbon and biodiversity scenarios generally result in greater intensification and less expansion of cropland, with the biodiversity scenario showing a stronger intensification effect. However, the impact of setting the targets impacts different world regions in different ways. Overall, both scenarios result in a larger tree area compared to the reference scenario, while the carbon scenario also yields more grassland area. The land systems simulated while accounting for these additional demand types show strong patterns of specialization and spatial segregation in the provisioning of goods and services in different world regions. Our results indicate the relevance of including demands for multiple different goods and services in global land change assessments.

1. Introduction

Large shares of the Earth's terrestrial surface have been transformed by humans. More than 75% of ice-free land shows signs of anthropogenic alterations (Ellis and Ramankutty, 2008). These alterations directly affect terrestrial carbon, biodiversity, food security and many other factors that are important for human wellbeing (Schmitz et al., 2012; Vié et al., 2009). The vast majority of anthropogenic disturbances have been made for agricultural purposes, i.e. the production of food, feed, and fiber (Ellis et al., 2010). With expected population growth, and an increase in wealth in several major world regions, food security, and thus agricultural production, will remain important in the near future. At the same time, policies increasingly acknowledge other services provided by the land, such as biodiversity protection and carbon sequestration (Goldemberg et al., 2014; Nepstad et al., 2014). This leads to new pressures on land resources, but also creates the need to change our ways of assessing land change by accounting for these multiple demands on increasingly scarce land resources.

The influence of greenhouse gas (GHG) emissions on global climate regimes is now widely acknowledged (IPCC, 2013). Recent estimates indicate that over 20% of the annual GHG emissions are directly related to agriculture, forestry, and other land uses (Metz et al., 2007; Tubiello et al., 2015). Several initiatives with the objective of reducing GHG emissions have been proposed and implemented at national, regional, and global scales. Examples are the Reducing Emissions from Deforestation and Forest Degradation program (REDD) (UN-REDD, 2011), the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC, 1992), the Clean Development Mechanism (CDM, 2006), and calls for carbon neutrality (Dhanda and Hartman, 2011). These initiatives aim to prevent GHG emissions from terrestrial sources and also to sequester atmospheric carbon in terrestrial sinks.

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http://dx.doi.org/10.1016/j.gloenvcha.2016.06.014
0959-3780/

Similar to GHG emissions, the importance of global biodiversity is now commonly accepted due to its role in maintaining proper ecosystem functioning (Cardinale et al., 2012). Biodiversity is strongly related to land cover and land use (Chaplin-Kramer et al., 2015). The IUCN reports that 86% of threatened birds and mammals experience habitat loss and degradation (IUCN, 2010), much of which can be attributed to agricultural expansion or intensification (Chaplin-Kramer et al., 2015). Therefore, several multinational initiatives have aimed to preserve and protect biodiversity, mainly through protecting natural habitats. For example, in 2000 the United Nations Millennium Development Goals called for a reduction in the rate of loss of biodiversity (UNDP, 2007). Another example is the Convention on Biological Diversity, which in 2010 established the Aichi biodiversity targets, a set of goals and targets put in place to protect and promote global biodiversity. Target 11 calls for 17% of terrestrial area (not including Antarctica) to be conserved and protected, specifically those areas where biodiversity is threatened. This equals 22.94 million km^2, or an area roughly equal to the size of Canada, China, and India combined. As protected areas grow, they will inherently limit the extent to which agricultural and urban land uses can expand, which will affect future land use patterns considerably.

Assessments of future land use and land cover change are frequently driven by demand for agriculture and forestry products (Prestele et al., 2016). For example, land change in the GLOBIOM integrated assessment model is driven primarily by production of food, forest fiber, and bioenergy (Havlik, 2012); in the CAPRI model, land use change is driven by a demand for agricultural products (Britz, 2013); in LandSHIFT, it is a combination of food and energy crops that drive changes (Schaldach et al., 2011); and MAgPIE includes demands for food, feed, livestock production, bioenergy, and in a recent application a price on GHG emissions (Humpenöder et al., 2014). Although scenarios are evaluated that contain biodiversity protection or afforestation for carbon sequestration, these land changes are often superimposed by assumptions and not simulated as an explicit demand which competes with demand for food and feed production. At the same time, the demands for services, such as climate change mitigation and biodiversity protection, are increasingly driving land use and land cover changes, mainly through the implementation of new policies or incentives (Wolff et al., 2015).

In this paper we assess how and to what extent the inclusion of alternative sets of demands on land resources influence future land use patterns and intensities in a global land change model. Specifically, we include demands for carbon storage and biodiversity protection. The results of our scenarios are analyzed in terms of changes in agricultural extent and intensity, as well as the changes in forest cover and grassland cover. This paper first introduces the model and experiments, then presents the results, and subsequently provides a discussion on the ways in which demands for multiple services can be included in global scale model-based assessments.

2. Methods

2.1. Simulating land system changes with the CLUMondo model

CLUMondo is a forward looking model that simulates land system changes in response to various types of exogenously defined demand (van Asselen and Verburg, 2013). Land systems refer to typical combinations of land uses and land use intensities, with each land system potentially providing multiple goods or services (van Asselen and Verburg, 2012). Each land system consists of a combination of cropland, grassland, tree cover, bare land, and built-up land. The amounts of each of these differ per land system, representing the typical land cover mosaic characteristic for the land system. To account for regional differences, the precise cover fractions of the same overall land system may differ per model world region. Hence the amount of tree area in a mosaic grassland and forest system can be different in Oceania and in Central America. Moreover, each land system produces a combination of goods and services, such as head of ruminant livestock, tons of crop products, and tons of carbon sequestered. The amount of goods and services provided differs from one land system to the other, depending on the area used for production as well as the intensity of management of these land systems. Land use intensities can also differ per model region. For example, the total crop production from intensive cropland systems in Western Europe is roughly three times higher than that from the same system in Southern Africa, thus accounting for the specific regional conditions and production systems.

In the CLUMondo model, land system changes are allocated based on local suitability, spatial restrictions, and the competition between land systems driven by the demands for different goods and services (van Asselen and Verburg, 2013). The local suitability is estimated by fitting empirical relationships between the current spatial occurrence of a given land system (i.e. the response variable) and a set of explanatory biophysical and socioeconomic variables to a logistic regression. Spatial restrictions represent specific constraints for specific land systems, such as protected areas that prohibit the expansion of urban land and biophysical conditions that limit agricultural activities. The competition between land systems is simulated based on the ability of land systems to supply the goods or services for which there is a demand. In a numerical algorithm, the competitive advantage of the different land systems is iteratively modified based on demands for goods and services that are not yet provided. When land systems have a competitive advantage in supplying multiple (undersupplied) demands the competitive advantages are added. A solution (equilibrium) is found when all demands are fulfilled by the allocated land systems. Hence, in contrast to some other land change models CLUMondo does not use a hierarchy or heuristic to handle trade-offs between competing demands.

The intensification of agricultural land systems is also influenced by the availability of land that may potentially be used for cropland. This influence accounts for the restricted land availability as well as the connection of farm practices to a specific location, for example due to residency and land ownership. This mechanism can stimulate agricultural intensification in the case of limited land availability for agricultural expansion. At the same time, if land that is suitable for agriculture is available in other locations within a region, expansion in those locations is preferred over intensification of marginal areas. Essentially, this effect simulates local deviations in land price, resulting from land scarcity in the local neighborhood. This incorporation of land availability is different from other land change models, as these often simulate land prices on a country or regional level without accounting for the local variation in land availability. The strength of this neighborhood mechanism is determined by a parameter. To some extent, the neighborhood effect may be sensitive to the specification of this parameter. To assess this, we conducted a sensitivity analysis for one world region, Southeast Asia. The sensitivity analysis (Fig. S1) shows that a higher weight attributed to this neighborhood effect results in stronger overall intensification. At the same time, the sensitivity analysis indicates that upon modest variations in the weight of this mechanism the outcomes only show relatively small differences.

The functioning of the CLUMondo model is described in more detail by van Asselen and Verburg (2013) while the model and