

Chapter 34

A Short Presentation of CLUMondo

J. van Vliet and P.H. Verburg

Abstract CLUMondo simulates changes in land systems in response to an exogenous demand, land system characteristics, and a series of biophysical and socioeconomic variables. Land systems are defined in terms of their land cover composition as well as land use intensity. As a consequence, land systems can be multifunctional and thus provide multiple different goods or services. Moreover, an increase in demand for, say, crop produce, can lead to cropland expansion, cropland intensification, or both. Here we explain the model algorithm, and illustrate the advantage of the land system approach over traditional land use models at the national and the global scale. CLUMondo is available as a free and open source model.

Keywords Land use change · Land use intensity · Land systems · Land use model · Ecosystem services

1 Introduction

Changes in land use and cover are made in response to demands for various goods and services provided by the land, such as food produce or providing shelter. Changes in these demands can result in land cover conversion, for example an increase in food demand may lead to a conversion from forests to cropland, and a growing population may lead to an increase in built-up area. However, these demands can also be satisfied by increasing the land use intensity of a given area of land. For example, the conversion of subsistence agriculture to market-oriented production is characterized by an increase in agricultural yields, while the area under cultivation doesn't necessarily change. Hence both subsistence cultivation

J. van Vliet (✉) · P.H. Verburg
Environmental Geography Group, Faculty of Earth and Life Sciences,
VU University Amsterdam, Amsterdam, The Netherlands
e-mail: jasper.van.vliet@vu.nl

P.H. Verburg
e-mail: peter.verburg@vu.nl

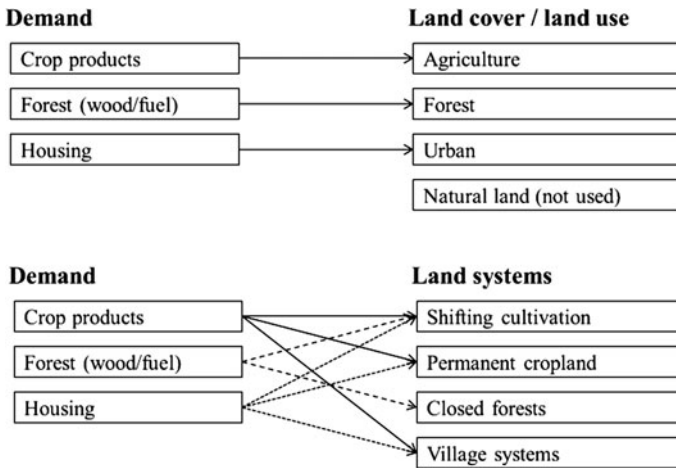


Fig. 1 Schematic representation of the relation between various demands, and changes in land uses or land systems. Conventional models (*top*) typically link one demand directly to one land cover or land use type, while CLUMondo (*bottom*) allows to link a demand to multiple different land systems and vice versa

and market based production are defined by the same land cover, namely cropland, while they differ in their land use intensity. These different intensities related the same land cover may have important, differential, impacts on climate (Luyssaert et al. 2014), biodiversity (Kleijn et al. 2009), water and soil quality (Keatley et al. 2011), and rural livelihoods (Cramb et al. 2009).

The CLUMondo model uses a land systems approach towards land change simulation. Land systems refer to typical combinations of land cover and their land use or management intensities (van Asselen and Verburg 2012), but may also contain information on the temporal and spatial configuration of the land system components. Each land system produces a specific combination of goods and services, such as tons of crop produce and head of livestock. Besides the provisioning of such commodities, also other services may be provided that are valued by society, such as water regulation and carbon sequestration (Wolff et al. 2015). Consequently, each good or service can be supplied by one or more different land systems, and one land system can supply one or more goods or services (see Fig. 1). This approach requires a different model representation than other models, where each land cover is typically driven by one (area) demand only.

2 Descriptions of the Methods Implemented

CLUMondo is a forward looking model that simulates land system changes in response to various types of exogenously defined demand and endogenously defined transition rules (van Asselen and Verburg 2013). Each simulation starts from an initial land systems map, which changes in yearly time steps. The user may

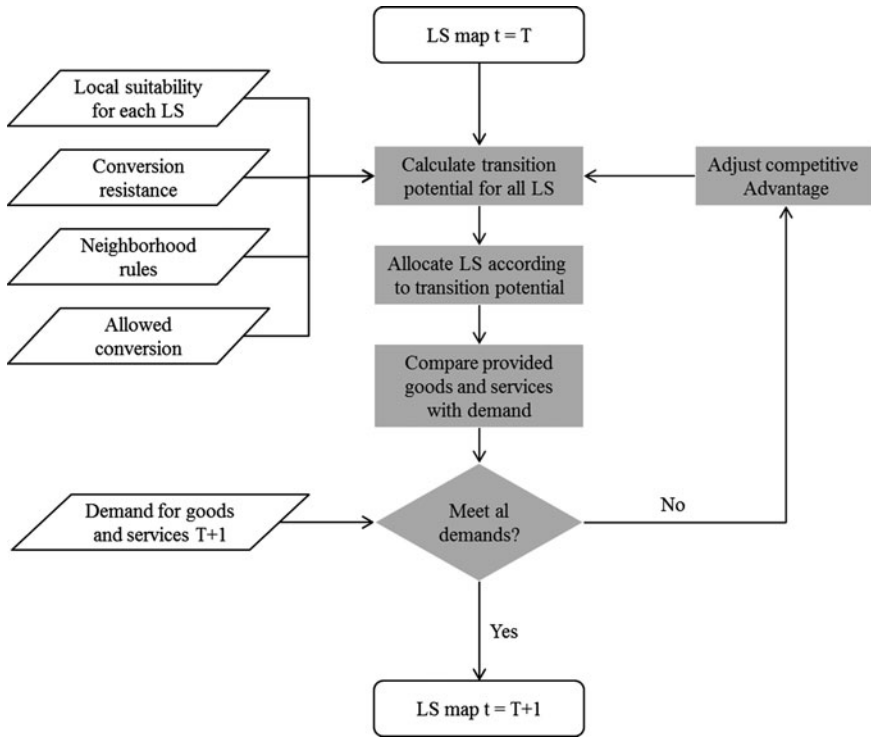


Fig. 2 Schematic overview of the land system (LS) allocation in CLUMondo. The grey boxes indicate the iterative loop for allocating LS changes within each time step

define whether demands for a particular year need to be met exactly (assuming an equilibrium) or whether they serve as minimum or maximum levels (such as indicating a minimum amount of carbon sequestration or a maximum amount of water extraction).

Within each yearly time step, land systems are allocated in an iterative procedure in which land systems are allocated according to the transition potential at time (t) and location (i) for each land system (LS), and the demands for goods and services for that specific year (see Fig. 2). The transition potential ($P_{trans_{t,i,LS}}$) is calculated as the sum of the local suitability ($P_{loc_{t,i,LS}}$), the conversion resistance ($P_{res_{LS}}$), the neighborhood effect ($P_{neigh_{t,i,LS}}$), and the competitive advantage of a land system ($P_{comp_{t,LS}}$) (van Asselen and Verburg 2013):

$$P_{trans_{t,i,LS}} = P_{loc_{t,i,LS}} + P_{res_{LS}} + P_{neigh_{t,i,LS}} + P_{comp_{t,LS}}$$

The local suitability of a location for a particular land system can be specified by the user or estimated based on current spatial patterns of different land systems. The latter employs one logistic regression model for each land system separately, where the occurrence of a land system is the dependent variable ($\beta_0, \beta_1, \dots, \beta_n$) while the

independent variables are a set of biophysical and socioeconomic conditions (f_1, f_2, \dots, f_n):

$$P_{loc} = \frac{1}{1 + e^{-(\beta_0 + \beta_1 f_1 + \beta_2 f_2 + \dots + \beta_n f_n)}}$$

Conversion resistance is an indication of the costs of converting a particular land system into any other system. Conversion costs are typically high for land systems with high capital investments and systems that are difficult to remove physically, such as urban and peri-urban systems. Extensive agricultural systems and (semi-) natural systems, on the other hand, are relatively easy to convert and are therefore typically characterized by a low conversion resistance. The conversion resistance is calibrated manually, based on expert knowledge, with values between 0 and 1.

The neighborhood effect represents the influence that land systems in the direct surroundings exert on the allocation of land systems. While the neighborhood effect is commonly used to simulate the mutual attraction of urban land uses (van Vliet et al. 2013), it can also be used to express the influence of land availability in the trade-off between cropland expansion and intensification (van Asselen and Verburg 2013). In this case it is assumed that under conditions of high land availability cropland expansion is possible, while intensification is induced when this is not the case. The neighborhood effect in CLUMondo is calculated as a function of the number of cells in the user-defined neighborhood, with land systems that contribute (f_{LS}), a constant (a), and a weight (w). The weight may be determined by the fraction of a specific land cover in a land system, e.g. to differentiate between land systems with a low and a high share of urban land cover. Note that the weight and the constant can be positive as well as negative. Therefore, the neighborhood effect can represent attraction, for example in urban agglomerations, and repulsion, for example due to limited land availability for cropland expansion.

$$P_{neigh} = a + w * f_{LS}$$

The competition between land systems is simulated based on ability of land systems to supply the goods or services for which there is a demand. Initially, the competitive advantage is 0 for each time step. This value is subsequently adjusted in an iterative procedure, 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 is found when all demands are fulfilled by the allocated land systems. Hence, in contrast to some other land use change models, CLUMondo does not use a hierarchy or heuristic to handle trade-offs between competing demands, but simulates their competition dynamically.

Other constraints on land allocation can be implemented in CLUMondo, and overrule the calculation of the transition potential as described above. Two important examples are whether specific conversions are allowed and the restrictions posed by spatial layers. The first typically reflects practical constraints for conversion, for

example to indicate that cropland cannot become a forest directly, as it takes several years and intermediate stages to grow trees (Verburg and Overmars 2009). The second represent specific constraints for the occurrence of land systems, such as natural parks that limit the expansion of urban land, or biophysical constraints that limit the expansion of cultivated areas (Eitelberg et al. 2015).

3 Applications

The CLUMondo model is flexible with regards to the scale, resolution, and the land systems to be considered. These model characteristics may be defined based on the needs of the study area and research questions at hand. However, the definition of land systems as typical combinations of land cover and land use intensities suggest a certain minimum resolution, as all components of a specific land system need to be included in the simulation unit. Consequently, CLUMondo is particularly well suited to simulate changes over relatively large areas. Current applications range from provincial to global scale. In this section we briefly present one national scale application and one global scale application.

Crop production in Laos takes place in a range of land systems with different intensities (Hett et al. 2012). Many villages, especially in less accessible places, are still dependent on subsistence agriculture, using swidden cultivation (Schmidt-Vogt et al. 2009). Other places, however, are characterized by permanent croplands, including paddy fields, and large scale plantations. As a consequence, an increased demand for food can be satisfied by changing relatively extensive swidden fields into more intensive permanent croplands, but also by cultivating new cropland areas. In our projections, intensification predominates in the near future (Ornetsmüller et al. 2016) (Fig. 3). This land change trajectory is a model result, as it was not specified a priori how the increased demand for food should be produced.

Globally, land systems differ in their land management intensity, but also in the goods and services they produce. Consequently, an increase in demand for crop products can lead to a cropland expansion but also to an intensification of existing cropland, depending on the local characteristics, the land system patterns to start with, as well as the availability of new land that can accommodate expansion (Eitelberg et al. 2015). However, land change is also increasingly driven by demands for other goods and services, for example carbon sequestration and biodiversity protection. As these demands are implemented through policy instruments, they are now drivers of land change, as well as consequences (Eitelberg et al. 2016). In the baseline scenario of this global application, land change is driven by a demand for crop production, head of ruminant livestock, and area of built-up land. Subsequently, we designed two alternative scenarios, that include an additional demand for carbon storage and biodiversity protection, respectively. As a result of the increased competition for land resources due to these additional demands, these scenarios yield more intensification and less expansion of cropland, and thus to more specialized land systems (see Fig. 4).

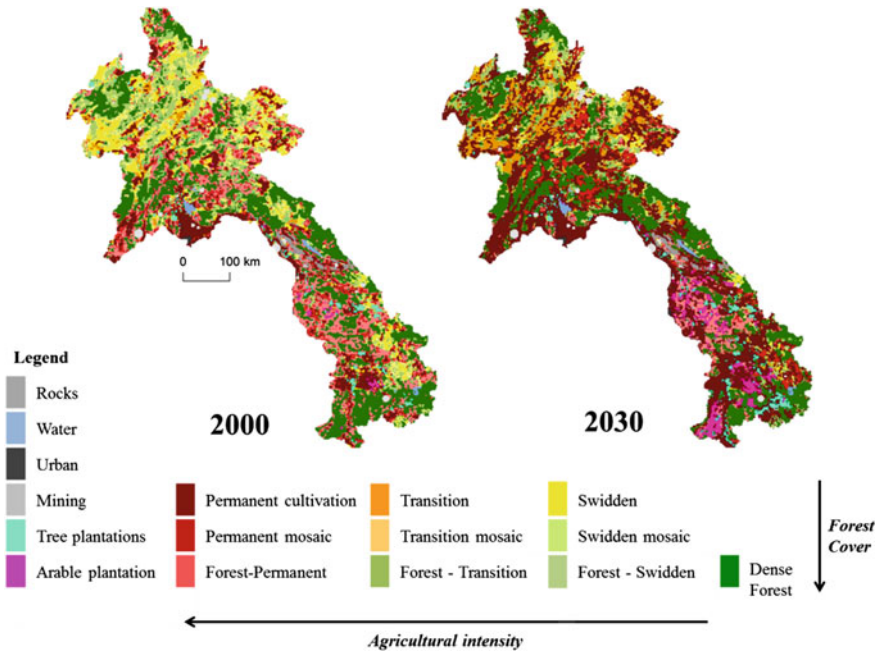


Fig. 3 Land systems in Laos in the years 2000 and 2030 (based on Ornetsmüller et al. 2016)

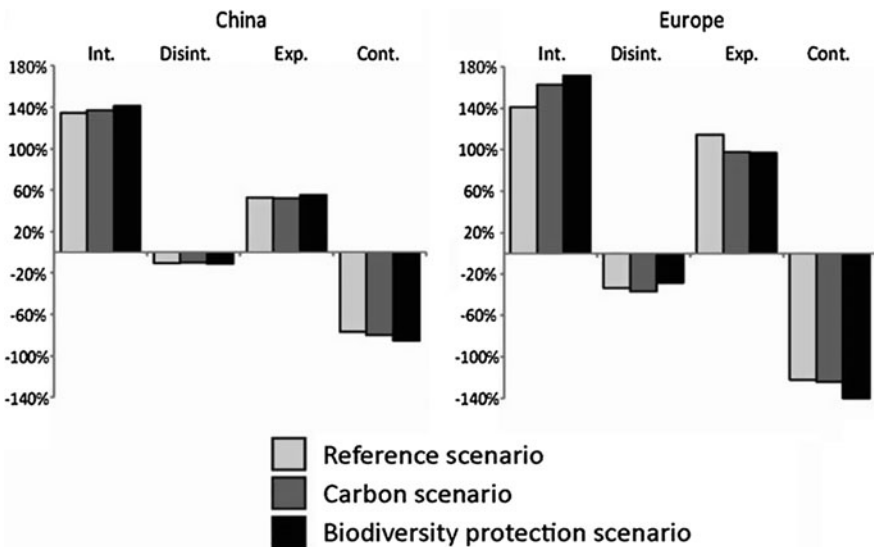


Fig. 4 Changes in crop production in various land change scenarios. The bars indicate the % change relative to the year 2000 for two selected model regions, illustrating the additional intensification caused by adding demand for carbon storage or biodiversity protection (based on Eitelberg et al. 2016)

4 Final Considerations and Technical Summary

Contrary to the representation in most models, land change is typically not driven by a demand for areas of land cover, but by a range of demands for goods and services provided by the land. These include food production, and housing, but increasingly also other demands, such as recreation, carbon storage, biodiversity, and disaster risk reduction (Wolff et al. 2015). The CLUMondo model is the first model that directly uses these demands as input for land change simulations. The examples provided in this chapter illustrate the two main advantages of this land systems approach. First, the representation of land systems allows for both expansion and intensification, in response to increased demand for food, as shown in Laos. Second, this approach allows to include multiple different demands, including those that are not linked to one land use strictly, such as carbon storage or biodiversity protection, as shown in our global application.

CLUMondo is available as a free and open source model from the dedicated webpage: <http://www.environmentalgeography.nl/site/data-models/models/>.

References

- Cramb RA, Colfer CJP, Dressler W, Laungaramsri P, Le QT, Mulyoutami E, Peluso NL, Wadley RL (2009) Swidden transformations and rural livelihoods in Southeast Asia. *Human Ecology* 37:323–346. doi:10.1007/s10745-009-9241-6
- Eitelberg DA, van Vliet J, Verburg PH (2015) A review of global potentially available cropland estimates and their consequences for model-based assessments. *Glob Chang Biol* 21:1236–1248. doi:10.1111/gcb.12733
- Eitelberg DA, van Vliet J, Doelman JC, Stehfest E, Verburg PH (2016) Demand for biodiversity protection and carbon storage as drivers of global land change scenarios. *Glob Environ Change* 40:101–111. doi:10.1016/j.gloenvcha.2016.06.014
- Hett C, Castella JC, Heinimann A, Messerli P, Pfund J-L (2012) A landscape mosaics approach for characterizing swidden systems from a REDD + perspective. *Appl Geogr* 32:608–618. doi:10.1016/j.apgeog.2011.07.011
- Keatley BE, Bennett EM, MacDonald GK, Taranu ZE, Gregory-Eaves I (2011) Land-use legacies are important determinants of lake eutrophication in the anthropocene. *PLoS ONE* 6(1): e15913. doi:10.1371/journal.pone.0015913
- Kleijn D et al (2009) On the relationship between farmland biodiversity and land-use intensity in Europe. *Proc R Soc B Biol Sci* 276:903–909. doi:10.1098/rspb.2008.1509
- Luyssaert S et al (2014) Land management and land-cover change have impacts of similar magnitude on surface temperature. *Nat Clim Chang* 4:389–393. doi:10.1038/nclimate2196
- Ornetsmüller C, Verburg PH, Heinimann A (2016) Scenarios of land system change in the Lao PDR: Transitions in response to alternative demands on goods and services provided by the land. *Appl Geogr* 75:1–11. doi:10.1016/j.apgeog.2016.07.010

- Schmidt-Vogt D, Leisz SJ, Mertz O, Heinemann A, Thiha T, Messerli P, Epprecht M, Van Cu P, Chi VK, Hardiono M, Dao TM (2009) An assessment of trends in the extent of swidden in Southeast Asia. *Human Ecology* 37:269–280. doi:[10.1007/s10745-009-9239-0](https://doi.org/10.1007/s10745-009-9239-0)
- van Asselen S, Verburg PH (2012) A Land System representation for global assessments and land-use modeling. *G Chang Biology* 18:3125–3148. doi:[10.1111/j.1365-2486.2012.02759.x](https://doi.org/10.1111/j.1365-2486.2012.02759.x)
- van Asselen S, Verburg PH (2013) Land cover change or land-use intensification: simulating land system change with a global-scale land change model. *Glob Chang Biol* 19:3648–3667. doi:[10.1111/gcb.12331](https://doi.org/10.1111/gcb.12331)
- van Vliet J, Naus N, van Lammeren RJ, Bregt AK, Hurkens J, van Delden H (2013) Measuring the neighbourhood effect to calibrate land use models. *Comput Environ Urban Syst* 41:55–64
- Verburg PH, Overmars KP (2009) Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landsc Ecol* 24:1167–1181. doi:[10.1007/s10980-009-9355-7](https://doi.org/10.1007/s10980-009-9355-7)
- Wolff S, Schulp CJE, Verburg PH (2015) Mapping ecosystem services demand: a review of current research and future perspectives. *Ecol Ind* 55:159–171. doi:[10.1016/j.ecolind.2015.03.016](https://doi.org/10.1016/j.ecolind.2015.03.016)