1.1 CLUE

1.1.1 Objectives CLUE within Eururalis

The CLUE modelling framework (the Conversion of Land Use and its Effects) is used in Eururalis to allocate the national level changes in land use to different locations within the 25 countries considered. The spatial allocation of land use change visualizes the effects of the scenarios for landscape pattern and enables the identification of hotspots of land use change, e.g., regions subject to relative large changes.
The spatial allocation explicitly takes the different spatial constraints and policies into account as well as the dynamics of underlying driving factors of land use change that influence the location of land use, such as demography, accessibility and climate.

1.1.2 Technical outline CLUE

Within the Eururalis project the CLUE-s 2.2b version of the CLUE modelling framework was used (Verburg et al., 2002; Verburg and Veldkamp, 2003) that allocates land use based upon a combination of dynamic simulation of competition between land use types, spatial restrictions, temporal trajectories of land conversions and empirical characterization of location suitability. The most recent version includes Cellular Automata as an optional simulation method to emulate spatially autocorrelated land use change processes such as urbanization (Verburg et al., 2004). The CLUE-s model is the most recent version of the CLUE modelling framework that was first published in 1996 (Veldkamp and Fresco, 1996) and has since that time been applied in at least 25 regions ranging between continental and local scales.

The model is divided into two distinct modules, namely a non-spatial demand module and a spatially explicit allocation module. In the non-spatial module, changes in area for the different land use types are calculated based on sectoral models (such as LEITAP in this application) or trend extrapolations and results in a specification of the area covered by the different land use types, on a yearly basis, for each country or each group of countries, which is a direct input for the allocation module.

In the spatial module, the land use demands are allocated to locations in the study area. The allocation is based upon a combination of empirical, spatial analysis and dynamic modelling. Besides the demands that are calculated in the projections and economic models, information on spatial policies and restrictions, land use type specific conversion settings and location characteristics is needed to run the model. A description of these information categories is given below (figure 5.8).

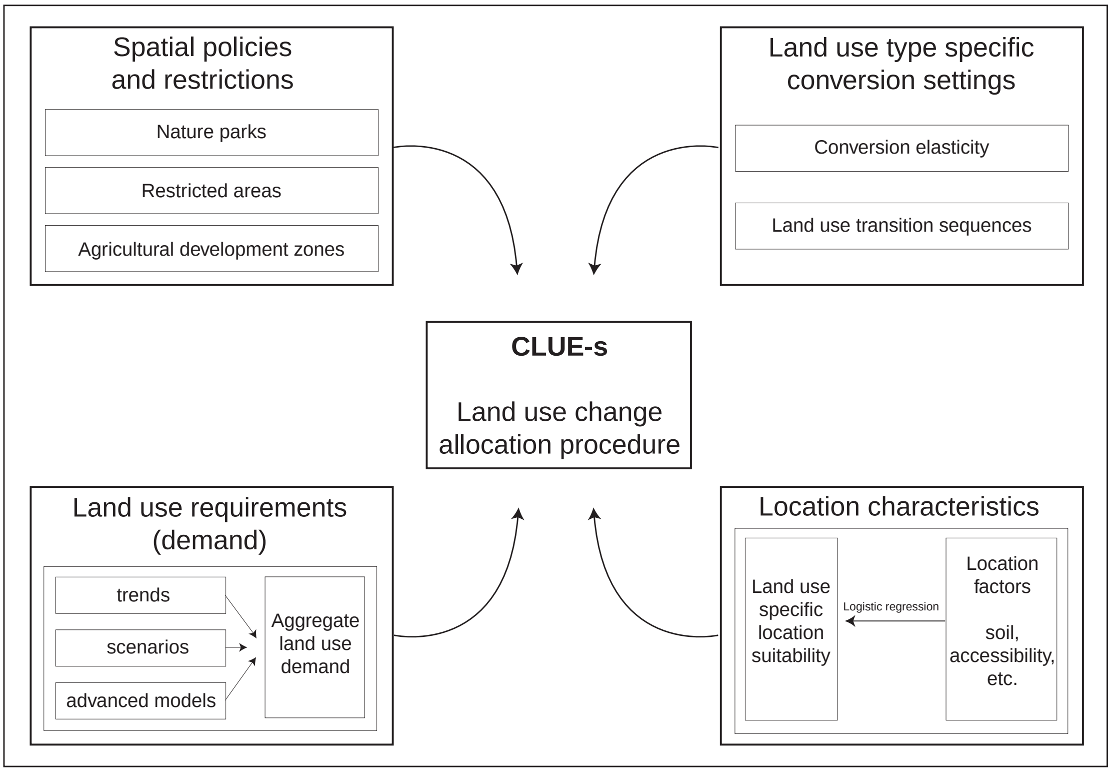

Figure 5.8. Overview of the information flow in the CLUE-s model

1.1.2.1 Spatial policies and restrictions

Spatial policies can influence the pattern of land use change. Spatial policies and restrictions mostly indicate areas where land use changes are restricted. Some spatial policies restrict all land use change in a certain area, e.g. to protect a national park. Other land use policies restrict specific land use conversions, e.g., residential construction in designated agricultural areas or permanent agriculture in the buffer zone of a nature reserve. To take into account these restrictions in modelling, maps that indicate the restricted areas must be supplied as input.

1.1.2.2 Land use type specific settings: conversions

The second category of data indicates which land use transitions are possible under which conditions. For this, two parameters are used: land use transition sequences and conversion elasticity's.

The land use transition sequences indicate which transitions are possible and what the temporal dynamics of the transitions are. For this, a conversion matrix is used (figure 5.9). This matrix defines to what other land use types the present land use type can be converted or not. Furthermore, region specific conversion settings and temporal restrictions can be indicated. Figure 5.9 provides an example of the use of a conversion matrix for a simplified situation with only three land use types.

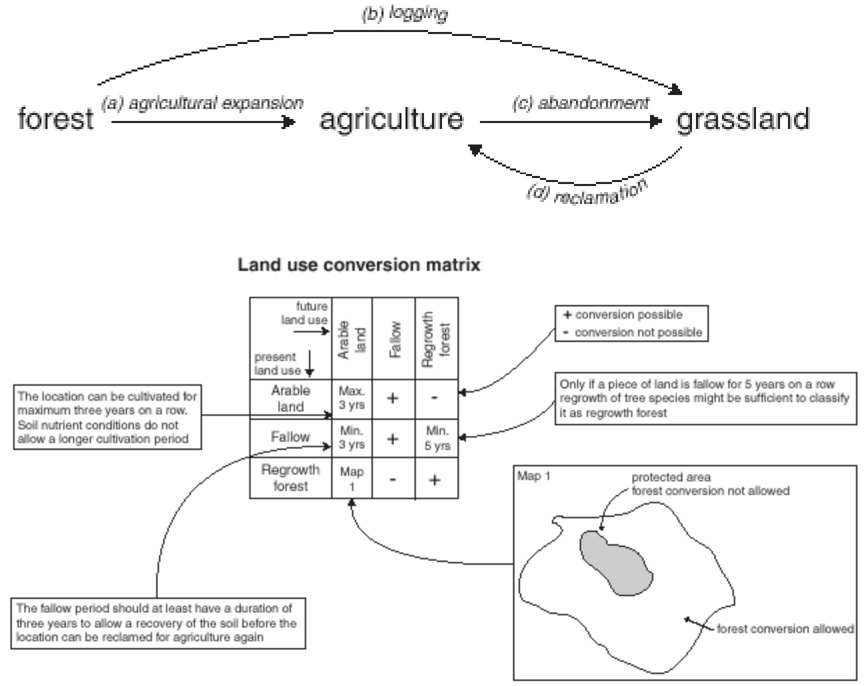

Figure 5.9. Example of land use transitions and conversion matrix.

Conversion elasticity's indicate the relative elasticity to change for each land use type. Land use changes with high capital investment (e.g. residential area, permanent crops) will not easily be converted in other uses as long as there is sufficient demand. Other land use types easily shift location when the location becomes more suitable for other land use types. Therefore, a value needs to be specified that represents the relative elasticity to change, ranging from 0 (easy conversion) to 1 (irreversible change). The user should decide on this factor based on expert knowledge or observed behaviour in the recent past.

1.1.2.3 Location characteristics

Land use conversions are expected to take place at locations with the highest 'preference' for the specific type of land use for that moment in time. Preference represents the outcome of the interaction between the different actors and decision-making processes that have resulted in a spatial land use configuration. The preference of a location is empirically estimated from a set of factors that are based on the different, disciplinary, understandings of the determinants of land use change. The preference is expressed as the probability of a grid cell for the occurrence of the considered land use. To use the location characteristics, maps of the biophysical and socio-economic location characteristics and regression equations that relate the probability with the location characteristics are used.
The drivers that are used in Eururalis are listed in table 1.

Table 5.2. Drivers used in Eururalis.

Constant drivers	Elevation Parent material Soil: suitability, texture, moisture Infrastructure: roads, railways, flight infrastructure, wet infrastructure Income Climate: temperature, precipitation
Drivers: Changing in time	Population: rural, urban, overall density, labour density, housing density, Accessibility
Restrictions	Natural parks Other restricted areas

1.1.2.4 Locations characteristics: Neighborhood interactions

Land use conversions can be explained, for a large part, by the occurrence of land uses in the neighborhood. For example, new urban area is more likely to develop at the fringe of existing urban area than elsewhere. To characterize the neighborhood of a location the enrichment factor (F) is used. This measure defines if a certain land use type is under-or over-represented in the neighborhood of a grid cell relative to the whole raster. The relation between neighborhood interactions and the land use patterns can be defined with regression equations in the same way as the biophysical and socio-economic location characteristics.
Especially in the context of urban growth, it is useful to include neighborhood interactions as a driving factor (Verburg et. al., 2003).

1.1.3 Allocation procedure

When all input is provided the CLUE-S model calculates, with discrete time steps, the most likely changes in land use given the before described restrictions and suitabilities. The allocation procedure is summarized in Figure 3. The following steps are taken to allocate the changes in land use:

1. Determination of all grid cells that are allowed to change. Grid cells that are either part of a protected area or presently under a land use type that is not allowed to change are excluded from further calculation. Also the locations where certain conversions are not allowed due to the specification of the conversion matrix are identified.
2. For each grid cell i the total probability (TPROPi,u) is calculated for each of the land use types u according to:
   $$TPROP_{i,u} = P_{i,u} + ELAS_u + ITER_u$$
   where Pi,u is the suitability of location i for land use type u, ELASu is the conversion elasticity for land use u and ITERu is an iteration variable that is specific to the land use type and indicative for the relative competitive strength of the land use type. Pi,u consists of a part based on the biophysical and socio-economic factors, and a neighbourhood interaction part.
3. A preliminary allocation is made with an equal value of the iteration variable (ITERu) for all land use types by allocating the land use type with the highest total probability for the considered grid cell. Conversions that are not allowed according to the conversion matrix are not allocated. This allocation process will cause a certain number of grid cells to change land use.
4. The total allocated area of each land use is now compared to the land use requirements (demand). For land use types where the allocated area is smaller than the demanded area the value of the iteration variable is increased. For land use types for which too much is allocated the value is decreased. Through this procedure it is possible that the local suitability based on the location factors is overruled by the iteration variable due to the differences in regional demand. The procedure followed balances the bottom-up allocation based on location suitability and the top-down allocation based on regional demand.

Steps 2 to 4 are repeated as long as the demands are not correctly allocated. When allocation equals demand the final map is saved and the calculations can continue for the next time step. Some of the allocated changes are irreversible while others are dependent on the changes in earlier time steps. Therefore, the simulations tend to result in complex, non-linear changes in land use pattern, characteristic for complex systems (CLUE-help).

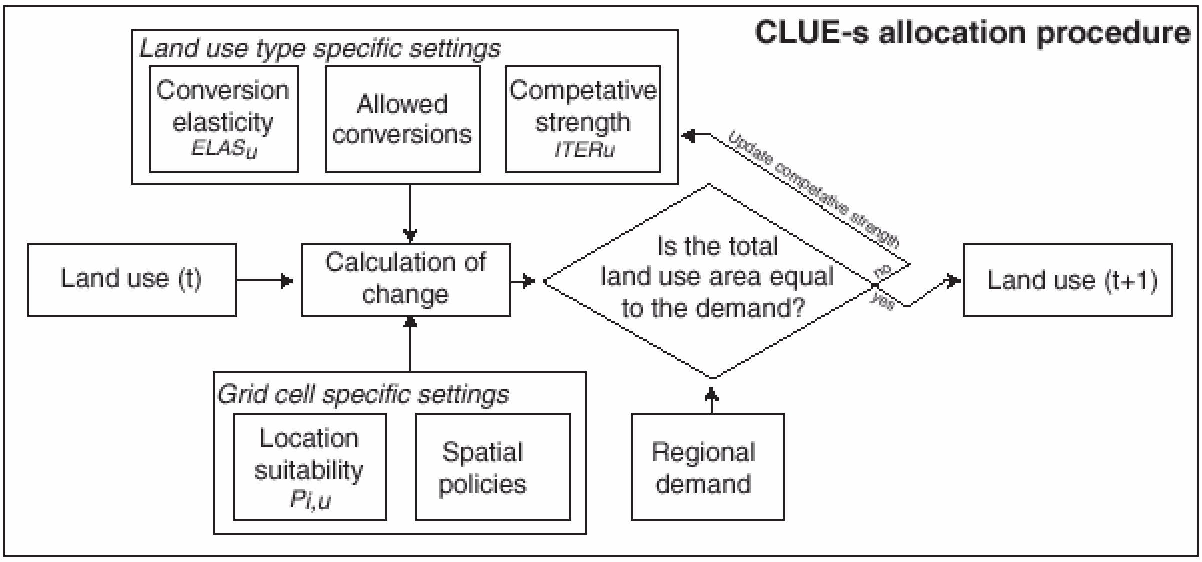

Figure 5.10. Flow chart of the allocation module of the CLUE-S model

1.1.4 Linkage to the GTAP and IMAGE model

The use off the calculated areas of arable land and permanent pasture calculated by the GTAP/IMAGE models is straightforward. However, for the other major land use types found in Europe the, scenario-dependent, changes in area are defined independently based on the scenario assumptions. A detailed explanation of the calculation of changes in residential area and nature area can be found in the documentation of the EURURALIS project. The resulting areas for all land use types are input to the CLUE-s allocation procedure. The temporal resolution of all CLUE simulations is 2 years.