ASTUS
Modelling urban sprawl with FORESIGHT and LUCSIM
Bauges Regional Nature Park study area

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Cerema

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1 Introduction

The EU-funded ASTUS project for Alpine Smart Transport and Urbanism Strategies has been broken down into various Work Packages (WPs) and divided up among different regional partners. WP2 consists of co-constructing low-carbon tools and developing decision aids for the pilot sites' projects and action, and making sure that the tools are transferable across Europe.

In the Auvergne-Rhône-Alpes region, ASTUS WP2 has set out to produce a CO2 minimiser tool as a transnational methodology for low-carbon scenarios, in cooperation with the TUM. There are also plans for Cerema Sud-Ouest to test urban sprawl modelling tools on the Thonon Conurbation and the Bauges Regional Nature Park areas.

For this more targeted initiative, the objectives are to:

- Develop a life-cycle costing approach to urban development, based on the costs generated by urban sprawl;
- Inform the development and mobility choices made by regional decision-makers by modelling the more or less long-term impact of their decisions on urban sprawl and land use;
- Test the software for modelling changes in land cover and land use on real-life examples, namely the Bauges Regional Nature Park and Thonon Conurbation areas.

This report describes the tests carried out and the results obtained for the Bauges Regional Nature Park study area.

A methodology report has also been produced, describing the operation of each tool and the tests performed.

2 Presentation of the software used

2.1 Choice of the type of modelling software

A preliminary opportunity study conducted by Cerema Sud-Ouest identified two main types of modelling tools suitable for use in the ASTUS project, based on the results they generate in terms of evaluating urban sprawl and changes in land use:

- Integrated land use and transport (LUTI) models). "An integrated land use and transport model is capable of simulating concurrent changes in land use and the transport system, since transport system efficiency is one of the variables on which households and businesses base their choice of location. An integrated model takes into consideration the fact that households pick their location on the basis of exogenous variables (an area's history) and endogenous variables (price, accessibility and amenities), and that both their choices and the variables are likely to change as a result of changes in the transport system and urban development policies"[1].
- Cellular automata (CA). In a cellular automaton model, the region is represented in its entirety by a network of cells, each of which is defined by a given state, such as a type of land use, which can then change over time in accordance with a series of rules known as transition rules.

The constraints laid down in the ASTUS project, notably in terms of implementation time frames and the goal of being able to transpose the methods and tools deployed in the test areas to European level, resulted in the fact that, while the LUTI models are perfectly suited to their modelling objectives, they are disproportionate and too unwieldy for use in this context.

Accordingly, we have chosen to use cellular automaton models instead: even if they cannot, in principle, answer all of the questions we might have, they are relatively easy to use and we know that we will be able to rapidly model different change scenarios for the area's land use. One of the main strengths of these models is that they can model complex behaviours on the basis of very simple operating rules.

[1] Mathieu Saujot (2013). Analyse économique et simulation prospective dans la planification de la ville sobre en carbone : Application à Grenoble du modèle TRANUS+. Économies et nuances. École Nationale Supérieure des Mines de Paris. 470 p.

2.2 Presentation of the two models chosen

For a detailed presentation of each tool, readers are referred to the methodology report.

2.2.1 FOREcasting Scenarios for citIes using GeograpHic daTa/FORESIGHT

Software name	FORESIGHT
Owner	Toulouse Tech Transfert (www.toulouse-tech-transfer.com)
References	Houet T., Aguejdad R., Doukari O., Battaia G., Clarke K., (2016) Description and validation of a 'non path-dependent' model for projecting contrasting urban growth futures, *Cybergeo*, 759 http://cybergeo.revues.org/27397
Licence	Paid (free when used for research or academic purposes)
Objective	To model various prospective urban-sprawl scenarios

2.2.1.1 Operating principle

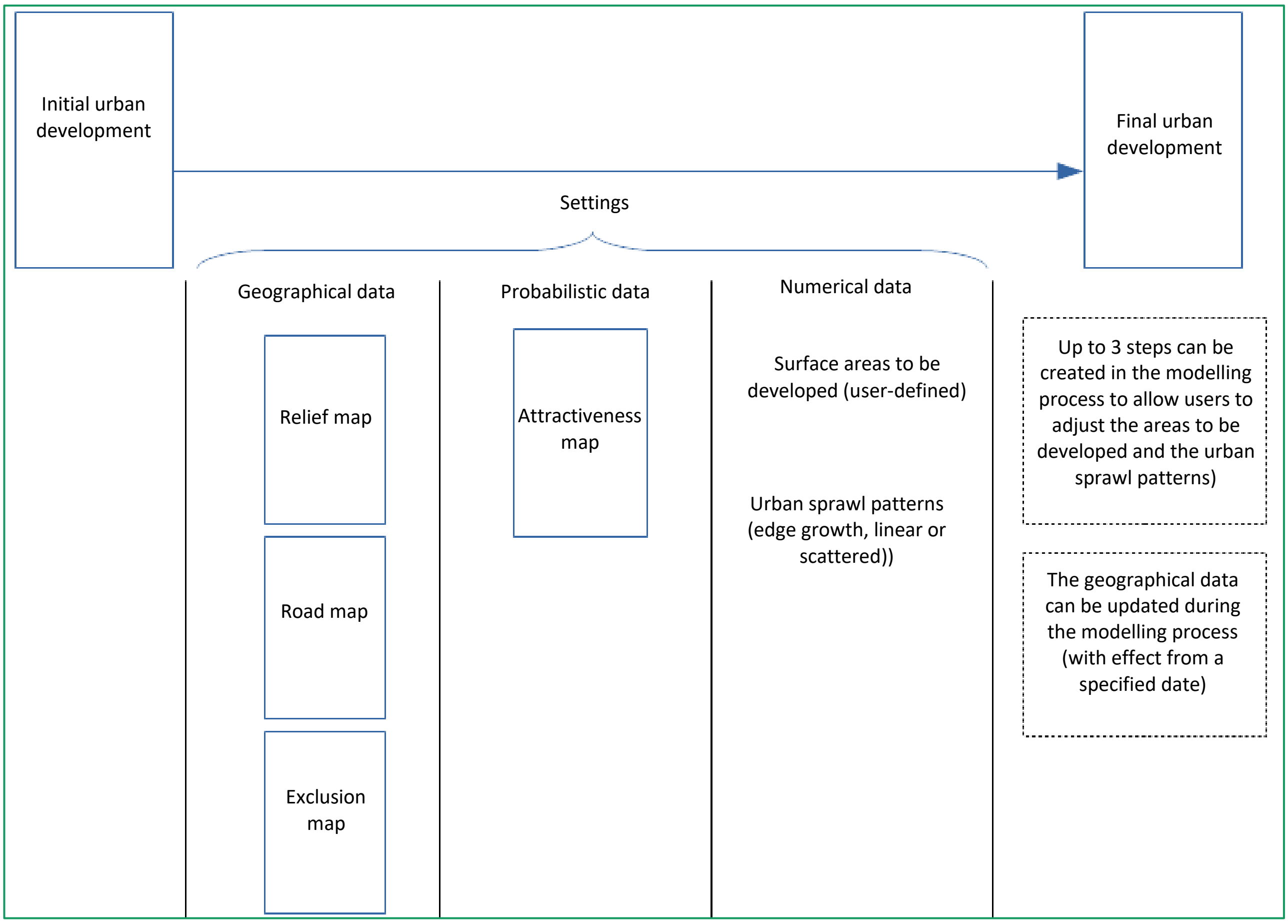

Figure 1: Block diagram of the FORESIGHT software

2.2.1.2 Input data

FORESIGHT has a pre-processing module for preparing the geographical input data.

- Initial Urban Map: map of the initial urban development (*.shp format; sources: Urban Atlas and CORINE Land Cover)
- Slope Map: relief map (raster format / sources: Shuttle Radar Topography Mission, IGN data)
- Hillshade: base map (raster format / sources: Shuttle Radar Topography Mission, IGN data)
- Road Map: map of the road network (*.shp format / source: OpenStreetMap)
- Excluded Map: exclusion map (*.shp format)
- Attractiveness Map: attractiveness map (a *.gif image that can be generated automatically by the FORESIGHT tool)

It is important to point out that, for both FORESIGHT and LUCSIM, only raster data can be processed, not images. The notion of urbanised or sealed area does not have any specific meaning for either of these programs: it is just one of a number of forms of land use. For this reason, the term "urban area" will be used throughout this report without any further explanation, as a general term encompassing urbanised areas in the sense of urban planning documents, urban footprint (whatever method is used to calculate it), sealed areas, etc.

2.2.1.3 Attractiveness map

This map is drawn up on the same methodological principle as a cost-distance map:

- Bear in mind that the "cost" of developing a pixel is not the same throughout the area: it will be higher in agricultural, forest or protected areas than in areas that have already been developed or areas earmarked for development in an urban planning document. Starting from a given point (or set of points and/or polygons) in the area, the software then assesses the cost entailed in moving from that particular point to any other point in the area, thereby establishing the cost of urban development at any point in the area.

FORESIGHT has a module that offers a simple way of drawing up an attractiveness map. The module factors in:

- Land use (sources: CLC or Urban Atlas): a friction factor can be defined for each land use class;
- The road network (source: OpenStreetMap): a friction factor can be defined for each type of road, to reflect the road network's influence as a vector of urban development;
- Points: the module can use a network of points or polygons to assess the cost of developing all of the pixels in the area.

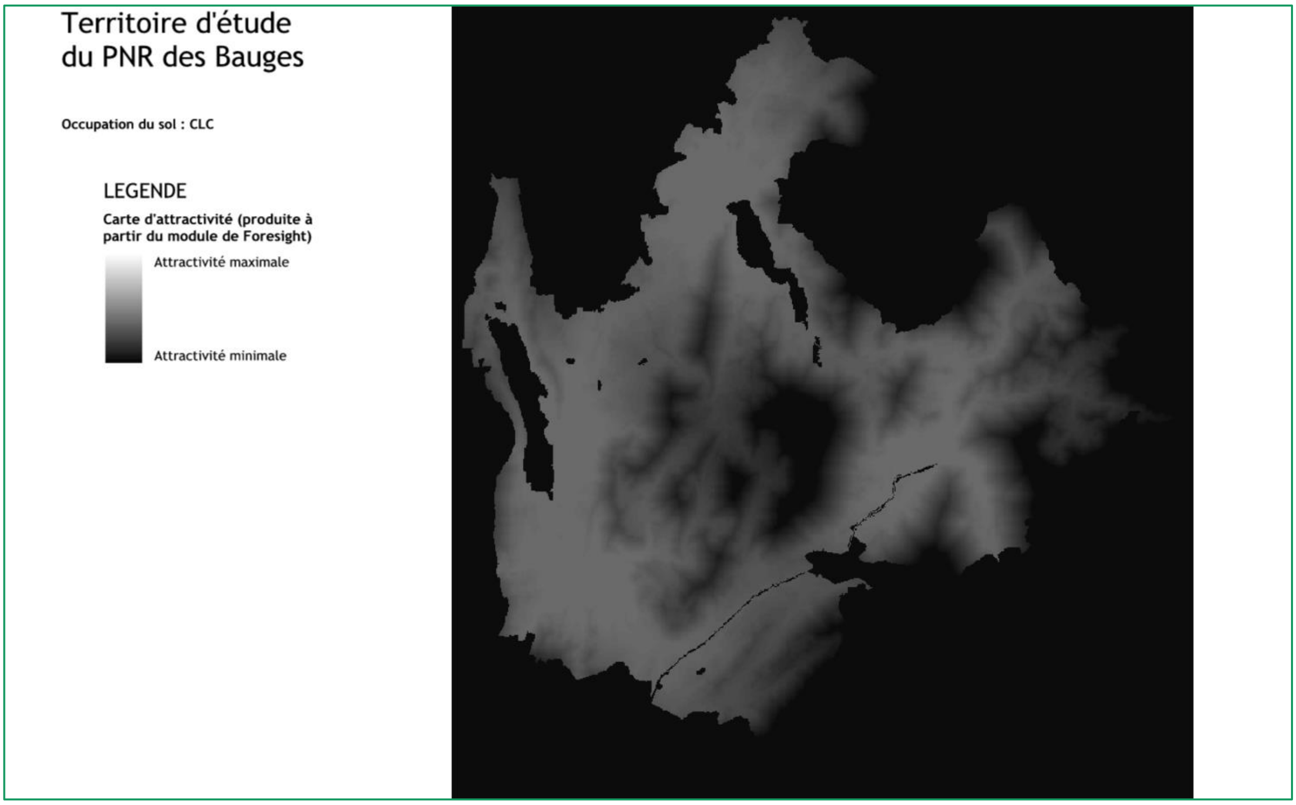

Figure 2: Attractiveness map produced with the dedicated FORESIGHT module (land use with CLC, roads with OSM) for the strategic scenario and for the Bauges Regional Nature Park study area

2.2.1.4 Settings

FORESIGHT provides the following settings for modelling urban sprawl between two given dates:

- Land take;
- Four urban sprawl patterns:
  - Spontaneous growth;
  - New spread center;
  - Road-influenced growth (linear development);
  - Edge growth (development that continues on from existing urbanisation).

In addition to these parameters, another two criteria are used to specify the influence of the relief and the road network on the preferred location for urban development.

It is possible to create up to three steps within a modelling process to allows users to change land take or the urban sprawl patterns.

FORESIGHT then allows users to incorporate a change in the mapping data (exclusion map, attractiveness map, road map) during the modelling process and specify the date from which the simulation module is to use the new data.

2.2.1.5 Output data

For a designated scenario, FORESIGHT models annual urban development or urban sprawl maps, along with a summary map that aggregates all of the information generated into a single map.

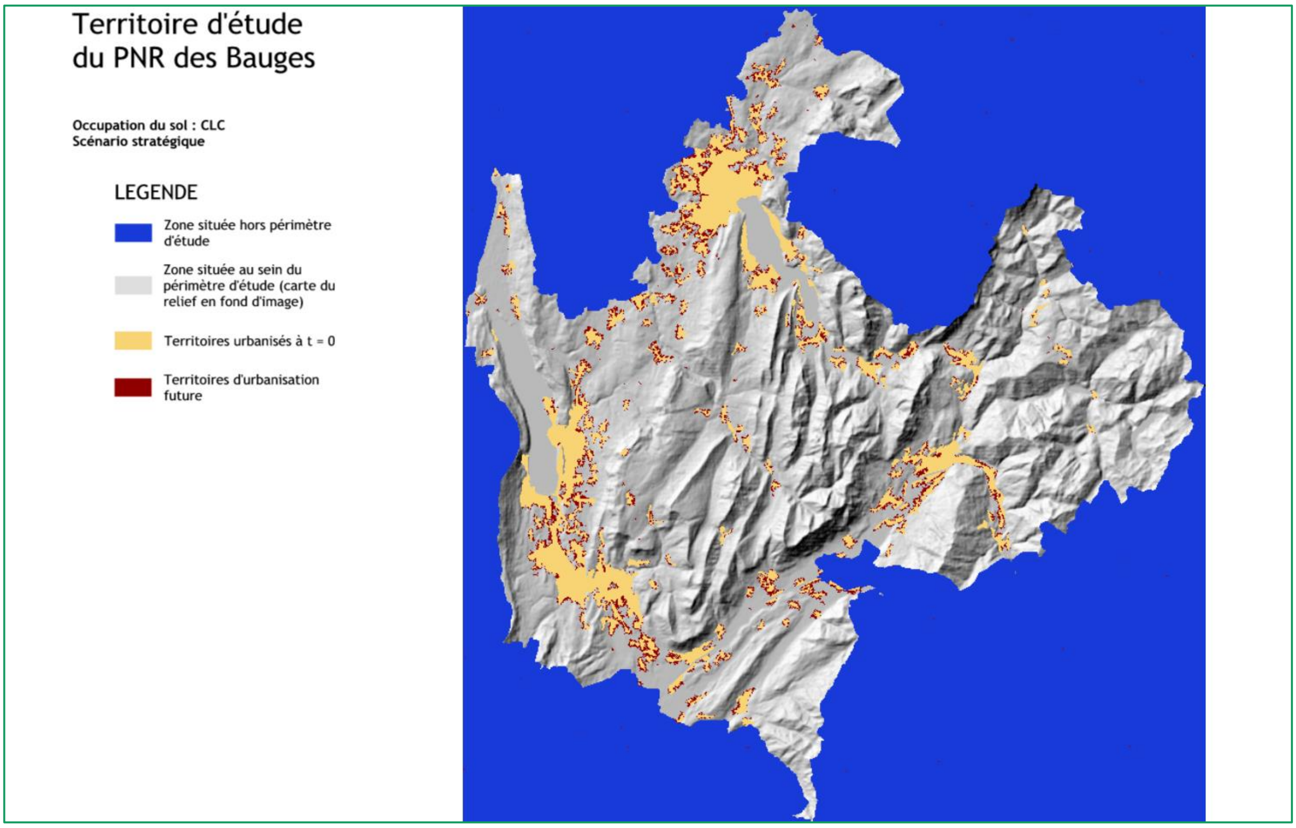

Figure 3: Model of urban sprawl through to 2050 in the Bauges Regional Nature Park study area (strategic scenario, CLC land use data)

For a given scenario, the software can generate a number of models.

The software also has a module that lets it aggregate the results of several scenarios or several modelling processes into a single urban growth probability map.

Based on various models, the software will generate a map showing the probability, for each pixel in the area, of the pixel being developed. This corresponds to the relationship between the number of models in which the pixel was developed and the total number of models taken into account.

This map can be generated, for example:

- From 20 models produced for a given scenario, using the *Scenario uncertainty* pane: we will then have information telling us, for a given scenario, for which sectors the probability of urban development is close to 100%, almost certain, and those for which the data is far more uncertain or random.
- From models generated by different scenarios: we will then have information telling us in which sectors urban development is highly likely to occur, whatever the area's change scenario.

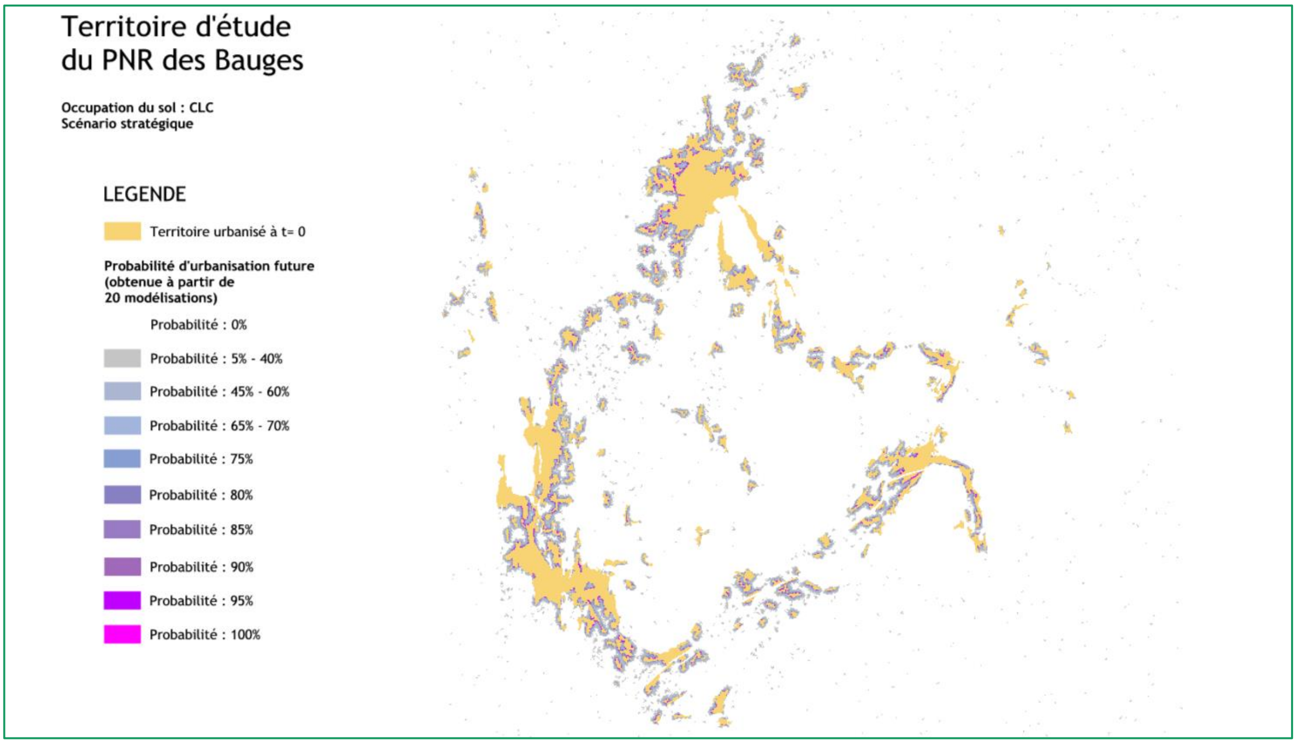

Figure 4: Probability of urban development, obtained from 20 models for the Bauges Regional Nature Park study area (strategic scenario, CLC land cover data).

2.2.2 Land Use Cellular Automata Simulation (LUCSIM)

Software name	LUCSIM
Owner	Université de Bourgogne-Franche-Comté / Laboratoire ThéMA
Website	https://sourcesup.renater.fr/LUCSIM/
Licence	GNU (free, open-source software)
Objective	Model changes in land use

2.2.2.1 Operating principle

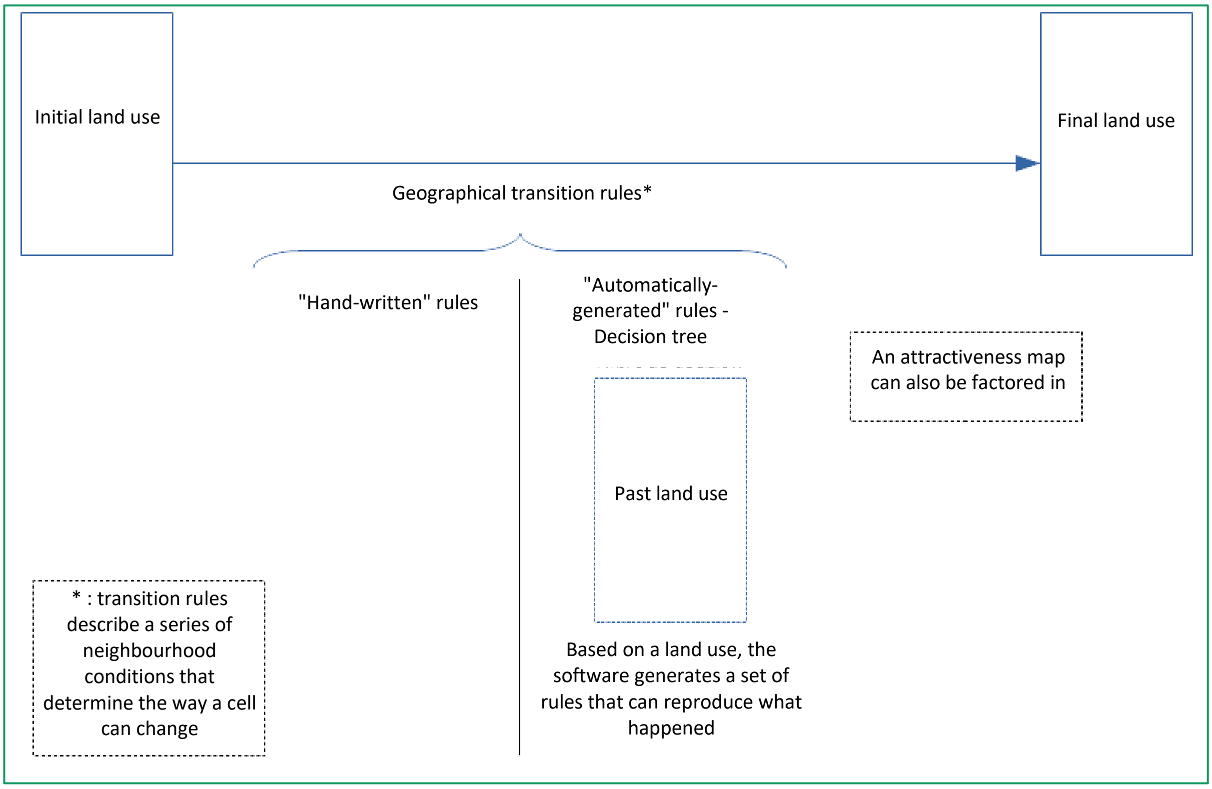

Figure 5: Block diagram of the LUCSIM software

2.2.2.2 Input data

To model changes in land use for a given area, users must have at least a land use map for a given date. These maps are *.tif images, in which the pixel codes correspond to different categories of land use.

To be able to use the decision tree to "automatically" generate transition rules, users need to have two maps in order to see how land use changed in the past and extrapolate its future developments.

Other raster layers, such as an attractiveness map or an exclusion map, can be added to guide the area's development.

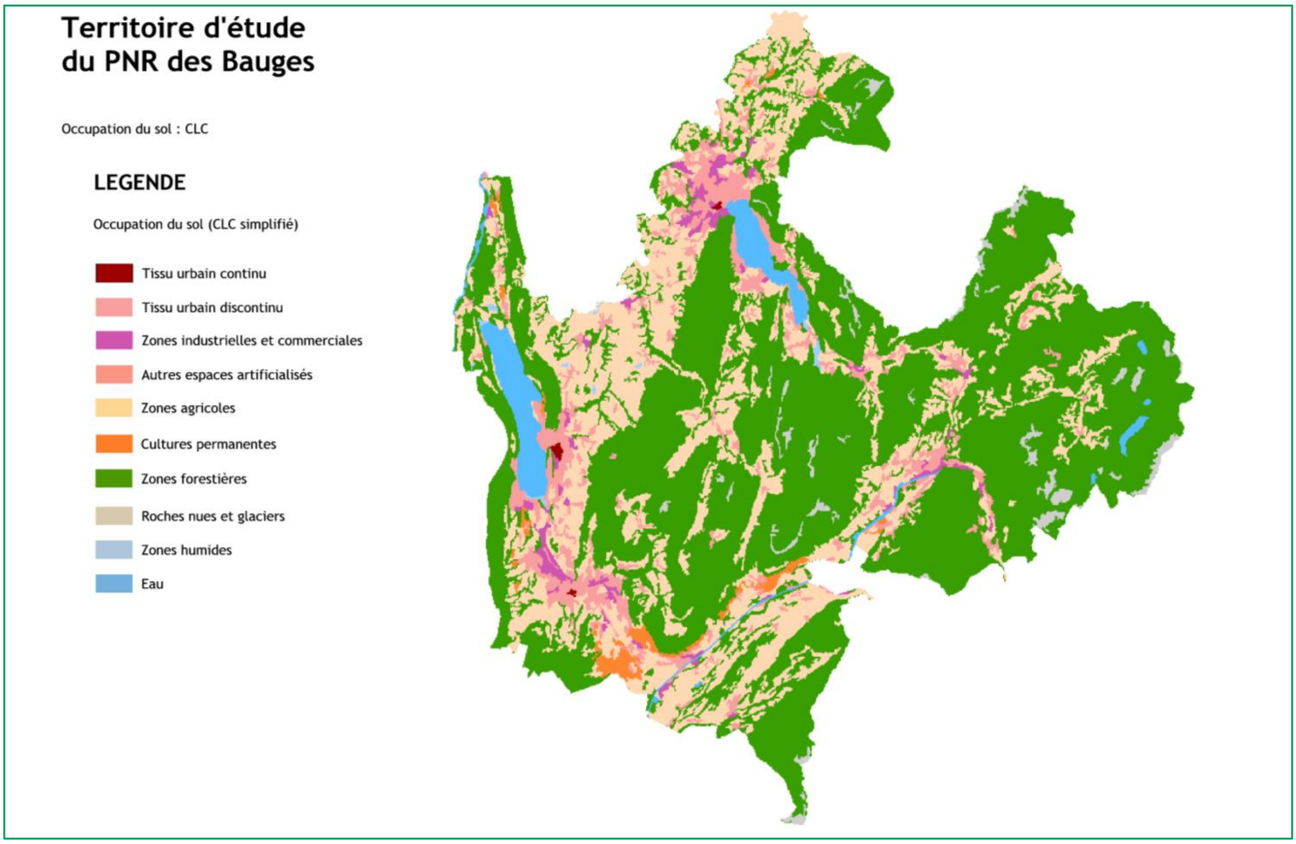

Figure 6: Land use (simplified CLC) in the Thonon Conurbation study area in 2012

2.2.2.3 Settings

The software provides a certain amount of statistical information and allows users to compare two land use layers.

To calibrate the modelling of changes in land use, users can set constraints on the modelling process, using:

- A potential model, which is equivalent to factoring in raster data such as an attractiveness map;
- A Markov chain, which limits changes in land use by predetermining the amounts of change that can occur, given the changes that can be seen between our two reference layers.

2.2.2.4 Writing transition rules

Transition rules are written with a special syntax that is specific to the software and uses 14 different functions. The tool has a module to assist with creating these rules.

Transition rules can be written by hand or determined "automatically" by the software with the help of a decision tree. Based on an analysis of the differences in land use between two different dates, the decision tree calculates transition rules, then applies these rules to reproduce the changes that occurred over this period as accurately as possible.

2.2.2.5 Output data

Once the transition rules have been established, the software is ready to model the changes that have occurred in the area.

There is no notion of time in the software. Each step of the modelling process comes to an end for one of the following reasons:

- At a given point, all of the pixels in an image can be changed;
- Not all of the rules can continue to be applied (the conditions are no longer fulfilled);
- The user has placed certain restrictions on the amount of changes possible, for example by using Markov chains.

3 Study programme – "What we planned to do!" »

3.1 Programme framework

In view of the ASTUS project's objectives and the way the two software programs to be tested operate, three key points guided the structure of the study programme assigned to the pilot sites:

- Use of different databases:
    - To ensure that the tests carried out on our test areas are transferable, at least one of the modelling tests must use European data sources, particularly for land use.
    - For more in-depth work on each of the areas, it is suggested that users use other data sources when possible.
- Modelling of different scenarios:
    - To be able to analyse the results obtained, it is important to remember that the purpose of these tools is not so much to represent a future image of the area as to enable a comparative spatial analysis of different simulations. The results are definitely not a prediction, which would be largely subject to debate as to why a particular sector was or was not developed.
    - For this reason, the objective should be to put forward different scenarios for the future development of the area, for use in each of the two software programs. Based on a handful of indicators, including land take and population growth, two scenarios should be drawn up: a baseline scenario and a strategic scenario. The scenario design should be informed by an analysis of the area's main strategic planning documents.
- Macroscopic modelling:
    - The FORESIGHT and LUCSIM software programs that will be used in the ASTUS project are both cellular automata tools. Because of the way they are built, these models cannot be used to model changes in land use on a very small scale (such as a land parcel or town district), since they do not reflect, in concrete terms, actual behaviour in the area. On the other hand, they are recognised for their ability to model land use changes on macroscopic scales.

3.2 Test strategy

3.2.1 Using FORESIGHT

We propose the following strategy for testing the FORESIGHT software:

- Use one or two land use databases:
  - CORINE Land Cover (CLC), 2012 edition
    - Land use database available with a spatial resolution of 100 m at European level. It has a detailed nomenclature broken down into three levels (five items for the first level, up to 44 items for the third level), available for the 1990, 2000, 2006 and 2012 editions.
  - OSCOM, 2013 edition (available only in the Auvergne-Rhône-Alpes Region)
    - Land use database developed by the DREAL Auvergne Rhône-Alpes. Only one edition available to date. It has a detailed nomenclature, broken down into two levels (five items for the first level, 15 for the second level), and a spatial resolution of 10 m.
- Model a baseline scenario and a strategic scenario. These two types of scenario will be differentiated by the following features:
  - Land take:
    - For the baseline scenario, land take will be established by continuing the trends observed between 2000 and 2012 in CLC.
    - For the strategic scenario, land take will be determined on the basis of data from the area's various strategy documents.
  - The area's attractiveness map:
    - Two attractiveness maps, one for each of the two scenarios, will be drawn up without using the dedicated module available in the FORESIGHT software.
    - For the baseline scenario, the attractiveness of the various urbanised areas will be adjusted on the basis of recent demographic trends. The attractiveness of the natural, agricultural and forest areas (implying a notion that is the opposite of friction) will be adjusted on the basis of the pace of land take between 2000 and 2012.
    - For the strategic scenario, the attractiveness of the various urbanised areas will be adjusted on the basis of the regional framework defined in the area's strategy documents. The attractiveness of the natural, agricultural and forest areas will be adjusted on the basis of an appraisal of the level of protection of these various areas included in the strategic documents used.
  - The urban sprawl patterns:
    - For the baseline scenario, the formula for distribution among the various *Patterns* will be based on an analysis of the changes in the area between 2000 and 2012, using CLC.
    - For the strategic scenario, the formula for distribution among the various *Patterns* will be adjusted on the basis of an appraisal of the information contained in the area's strategy documents.

3.2.2 Using LUCSIM

We propose the following strategy for testing the LUCSIM software:

- Writing the rules "by hand" would require extensive discussion between the area's authorities and Cerema to agree on the rules to be modelled. Given that this task cannot be undertaken as part of the ASTUS project, the software will be used in "automatic" mode.
- Different land use databases will be used, bearing in mind that using the software in "automatic" mode requires access to at least two editions:
    - CORINE Land Cover, 2000 and 2012 editions, spatial resolution of 100 m;
    - High Resolution Layers (HRL), spatial resolution of 20 m;
        - This data is produced by the EU-funded Copernicus programme (which supplied the CLC data). The data is available in four raster layers (sealed areas, forests, pastures, wetlands and water bodies), with a level of definition significantly higher than that of CLC. There are several editions for sealed areas (2006, 2009, 2012 and 2015), but only one edition for all of the other types of land use (2015)[2].
    - Theïa
        - Theïa publishes a land use database for France as a whole, using Landsat 5 satellite data for the 2009, 2010, 2011 and 2014 editions, and Landsat 8 and Sentinelle 2 data for the 2016 and 2017 editions. The latter has a 10 m level of resolution (30 m for Landsat 5) and the layer is based on a 17-category nomenclature[3].
- The test program will model a "baseline" scenario calculated by the software and a "strategic" scenario adapted from the strategic scenario developed for FORESIGHT:
    - The "baseline" scenario will use the LUCSIM software in "automatic" mode. Modelling will be constrained by a Markov chain, sized to match the urban sprawl surface area in the baseline scenario drawn up for FORESIGHT.
    - The "strategic" scenario will also use the LUCSIM software in "automatic" mode. Modelling will be constrained by a Markov chain, sized to match the urban sprawl surface area in the strategic scenario drawn up for FORESIGHT, and by the attractiveness map drawn up for the same scenario. Given the uncertainty as to whether our attractiveness map will be taken into account by the model, the *Potential model* will also be used to adapt our strategic scenario to the LUCSIM software.

[2] The 2012 edition has since been published on the Copernicus website on 21 June 2018.
[3] The 2016 and 2017 data has been available since June 2018 in dual raster and vector format.

4 Presentation of the study area and the content of the scenarios

The strategic and baseline scenarios used to test the modelling programs are not part of a long-term forecasting approach. Nevertheless, it seemed important to provide a brief description of their content in order to give them a certain internal consistency that reflects a potential future development of the area. This section contains a summary of:

- The diagnostic data: the study area's main features and trends in terms of population growth, housing and land use.
- The baseline and strategic data: projected population growth and land take figures, and the estimated level of protection of natural, agricultural and forest areas. The data for the baseline scenario will be estimated from the observable trends in the area. For the strategic scenario, the data will be extracted from the area's main strategic urban development documents.

4.1 Regional data

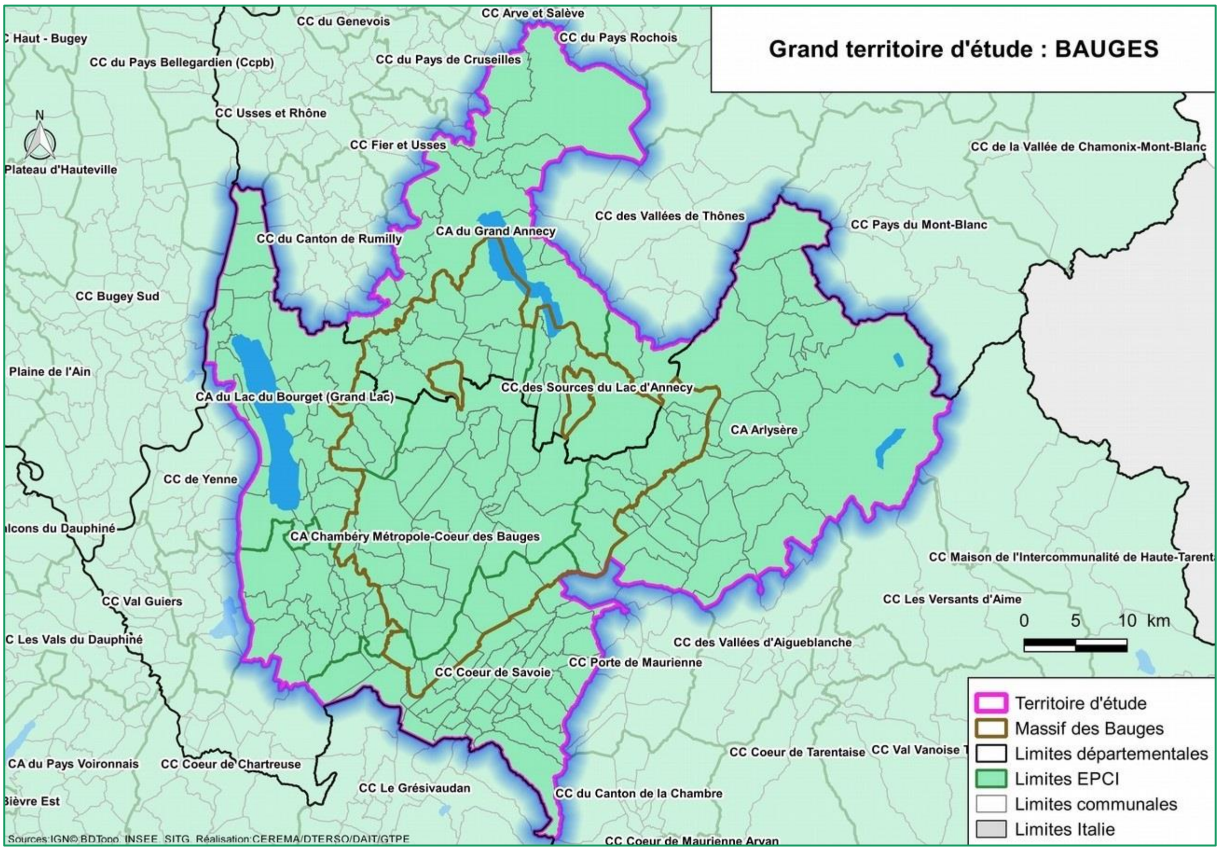

Figure 7: Study area

The study area includes the whole of the Bauges Regional Nature Park and borders on six *EPCI* (public inter-municipal cooperation establishments), namely:

- Communauté d'Agglomération Grand Lac;
- Communauté d'Agglomération Chambéry Métropole-Coeur des Bauges;
- Communauté d'Agglomération Arlysère;
- Communauté d'Agglomération du Grand Annecy;
- Communauté de Communes Coeur de Savoie;
- Communauté de Communes des Sources du Lac d'Annecy.

This area covers 188 municipalities.

4.1.1 Population growth

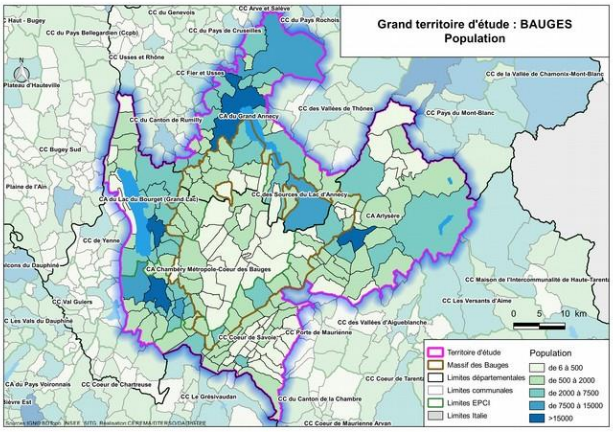

Figure 8: Population of the municipality in 2014 (INSEE)

Study area: 513,153 inhabitants

Grand Annecy conurbation community: 196,332 inhabitants
Arlysère conurbation community: 60,101 inhabitants
Grand Lac conurbation community: 73,665 inhabitants
Chambery Métropole-Coeur de Savoie conurbation community: 132,046 inhabitants
Coeur de Savoie community of municipalities: 35,895 inhabitants
Sources du Lac d'Annecy community of municipalities: 15,114 inhabitants

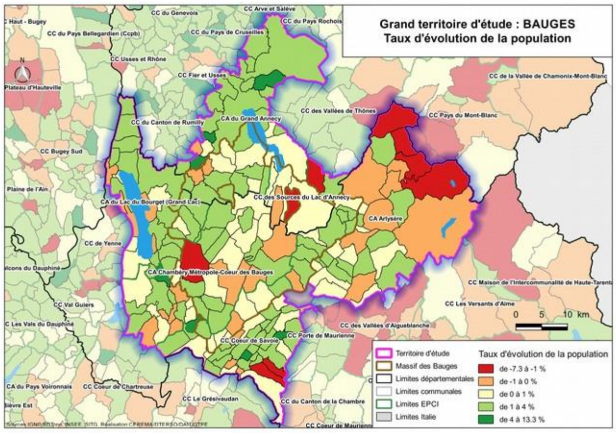

Figure 9: Annual municipal population growth rate between 2009 and 2014 (INSEE)

Study area: 1.22%

Grand Annecy conurbation community: 1.52%
Arlysère conurbation community: 0.38%
Grand Lac conurbation community: 1.96%
Chambery Métropole-Coeur de Savoie conurbation community: 0.89%
Coeur de Savoie community of municipalities: 1.05%
Sources du Lac d'Annecy community of municipalities: 0.78%

4.1.2 Dwellings

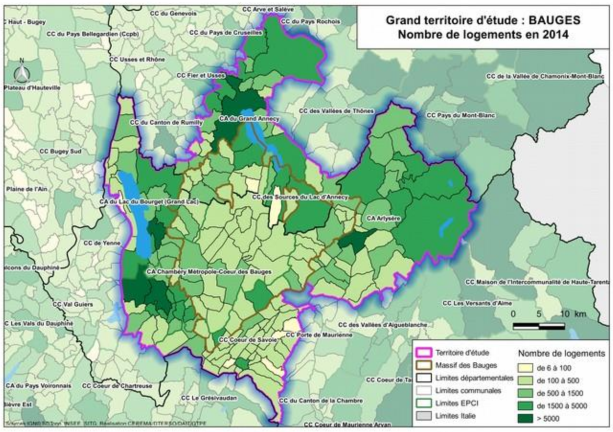

Figure 10: Number of dwellings in 2014 (INSEE)

Study area: 277,918 dwellings

Grand Annecy conurbation community: 100,635 dwellings
Arlysère conurbation community: 42,383 dwellings
Grand Lac conurbation community: 40,935 dwellings
Chambery Métropole-Coeur de Savoie conurbation community: 68,449 dwellings
Coeur de Savoie community of municipalities: 17,288 dwellings
Sources du Lac d'Annecy community of municipalities: 8,228 dwellings

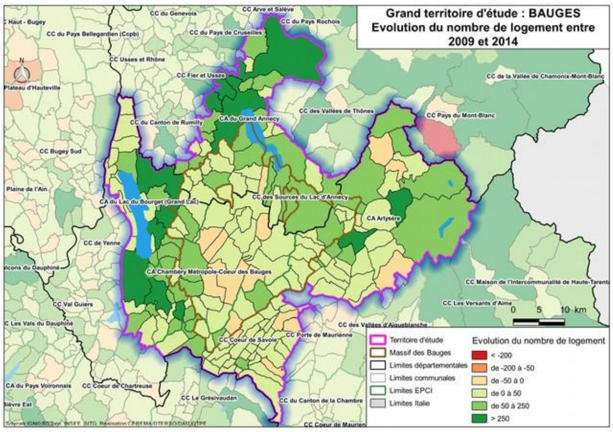

Figure 11: Increase in the number of dwellings between 2009 and 2014 (INSEE)

Study area: +21,392 dwellings (+1.6%/year)

Grand Annecy conurbation community: +8,222 dwellings (+1.8%/year)
Arlysère conurbation community: +3,028 dwellings (+1.5%/year)
Grand Lac conurbation community: 3,807 dwellings (+2.0%/year)
Chambery Métropole-Coeur de Savoie conurbation community: +4,259 dwellings (+1.3%/year)
Coeur de Savoie community of municipalities: +1,247 dwellings (+1.5%/year)
Sources du Lac d'Annecy community of municipalities: + 559 dwellings (+1.4%/year)

4.1.3 Land use and land take

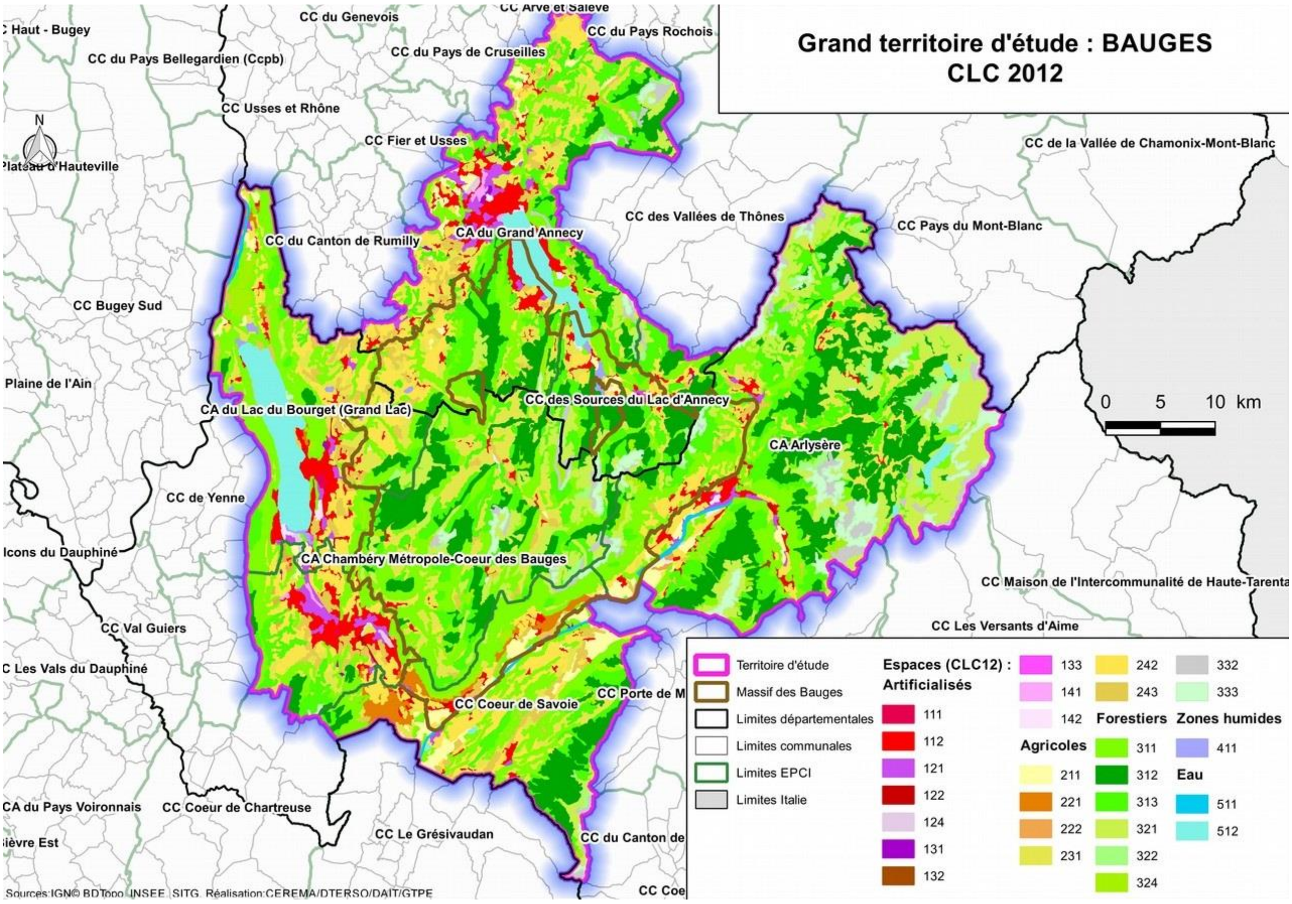

Figure 12: CLC 2012

Based on CLC 2012 data, surface area of sealed land (proportion of sealed land) **Study area: 23,041 ha (8.7%)** Grand Annecy conurbation community: 7,723 ha (14.4%) Arlysère conurbation community: 3,495 ha (4.6%) Grand Lac conurbation community: 4,138 ha (11.9%) Chambery Métropole-Coeur de Savoie conurbation community: 4,789 ha (9.2%) Coeur de Savoie community of municipalities: 1,849 ha (5.6%) Sources du Lac d'Annecy community of municipalities: 1,046 ha (6.9%) Study area (Switzerland): 12,577 ha	Based on CLC 2012 data, area of agricultural land (share of agricultural land) **Study area: 71,707 ha (27.0%)** Grand Annecy conurbation community: 19,040 ha (35.4%) Arlysère conurbation community: 11,222 ha (14.7%) Grand Lac conurbation community: 11,386 ha (32.7%) Chambery Métropole-Coeur de Savoie conurbation community: 13,840 ha (26.5%) Coeur de Savoie community of municipalities: 13,841 ha (41.9%) Sources du Lac d'Annecy community of municipalities: 2,379 ha (15.6%)	Based on CLC 2012 data, area of forest land (share of forest land) **Study area: 161,924 ha (60.9%)** Grand Annecy conurbation community: 24,498 ha (45.6%) Arlysère conurbation community: 60,971 ha (79.7%) Grand Lac conurbation community: 14,339 ha (41.1%) Chambery Métropole-Coeur de Savoie conurbation community: 33,680 ha (64.4%) Coeur de Savoie community of municipalities: 16,991 ha (51.4%) Sources du Lac d'Annecy community of municipalities: 11,446 ha (75.0%)

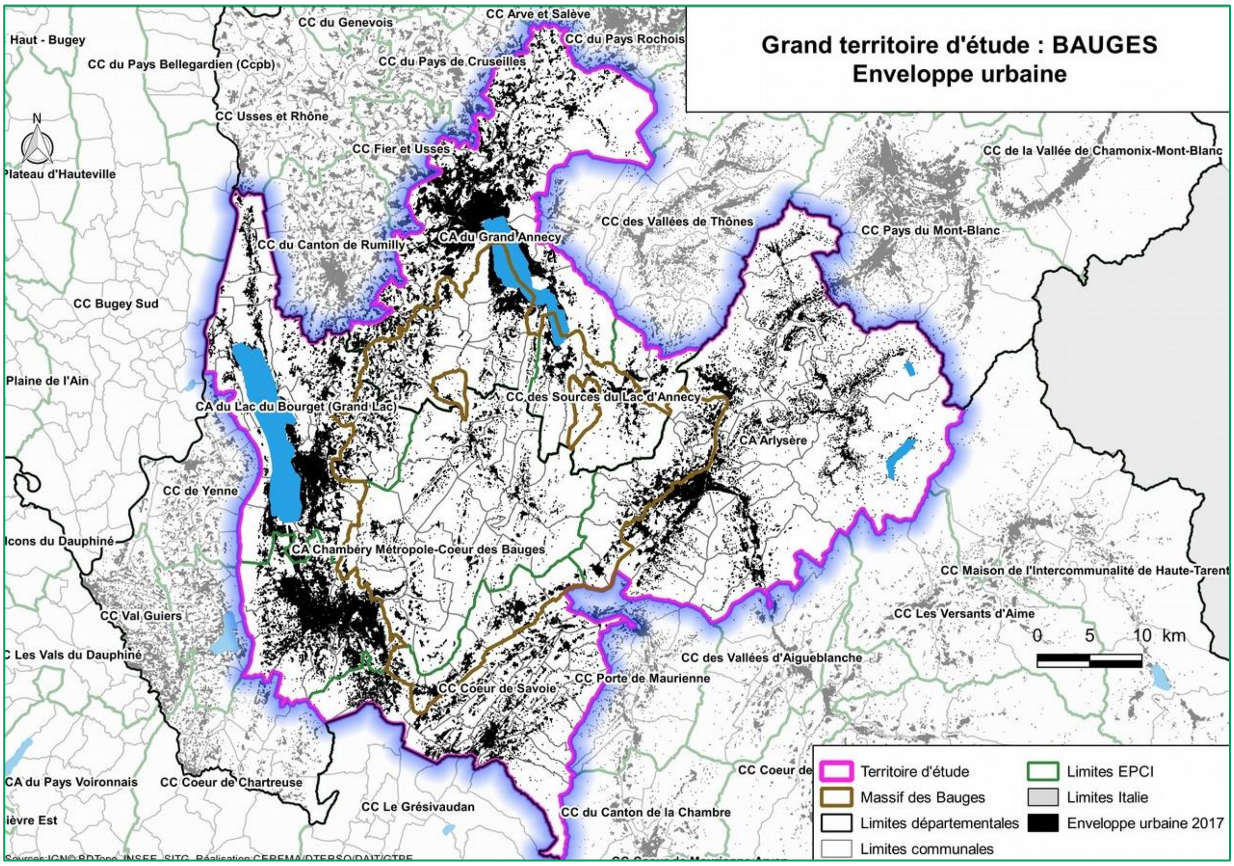

Figure 13: Urban extent in 2017

For the study area, the urban footprint in 2017, calculated from the topography database (Cerema Sud-Ouest method), is 19,247 ha. This is 1,618 ha more than in 2009.

4.2 Baseline scenario

4.2.1 Population growth

The total population of the study area in 2014 was 513,153 inhabitants. If we focus solely on the population growth in this area since 1968 and project population growth up until 2050 (polynomial projection), we arrive at a total population of 656,500 in 2050, representing a population increase of over 143,000 inhabitants between 2014 and 2050.

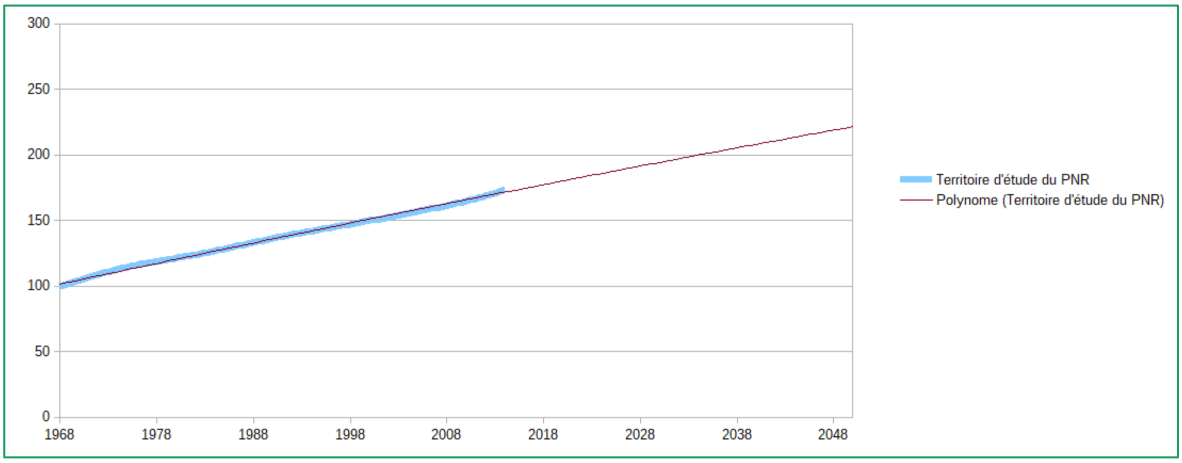

Figure 14: Population growth in the Bauges Regional Nature Park study area (base of 100 in 1968) and projection to 2050

We will use the following hypothesis for the baseline scenario:

- Projected population growth: 656,500 inhabitants in 2050 (+143,000 inhabitants between 2014 and 2050).

4.2.2 Land take

Based on CLC data, there were 23,041 ha of sealed areas in 2012, compared with 20,862 ha in 2000. This gives a total increase of 2,179 ha between 2000 and 2012 (+0.83% per year).

If this trend continues, land take will reach 6,900 ha by 2050 (extent of sealed areas in 2050: 29,941 ha).

Based on our calculations, we have an urban footprint of 19,247 ha in 2017, an increase of 1,618 ha since 2009. If land take continues at this rate, the outlook for 2050 is an urban footprint of 25,921 ha, which represents 6,674 ha of land take between 2017 and 2050. Based on this figure, we find a land take figure of the same magnitude as the figure calculated from CLC data for the period between 2000 and 2012.

We have therefore adopted the projection calculated with the data for 2000-2012, which gives us a land take figure of 6,900 ha, rounded up to 7,000 ha, for the period 2012-2050.

Based on the 2000 and 2012 editions of the CLC data, nearly 2,200 ha of land were converted into sealed areas, practically all of it taken from agricultural, forest and semi-natural areas. All in all, nearly 3.7 times more agricultural land was converted during this period than forest or semi-natural land.

4.3 Strategic scenario

To construct the strategic scenario, we drew on the following urban planning documents, which together cover the entire study area:

- SCoT Albanais;
- SCoT Arlysère;
- SCoT Bassin Annecien;
- SCoT Métropole Savoie;
- PLUi Coeur des Bauges.

Other documents were also consulted:

- PLUi Sources du lac d'Annecy;
- PLUi Pays d'Alby;
- Charte du PNR des Bauges;
- Diagnosis conducted as part of WP1 of the ASTUS project.

To construct the figures in the strategic scenario (projected population growth and land take), we relied exclusively on the documents analysed to generate projections up to 2050 by continuing the trends described in these documents, even if the latter were not established at the same period nor for the same projection time frames.

4.3.1 Population growth

Source document	Baseline	Goal	Projection to 2050
SCoT Albanais	20004 (approved in 2005)	+12,000 to +15,000 inhabitants in 20 yrs	
SCoT Arlysère	2010 (approved in 2012)	+8,000 inhabitants in 10 yrs (2010-2020)[4]	
SCoT Bassin Annecien	2014 (approved in 2014)	+40,000 inhabitants in 20 yrs [5]	
SCoT Métropole Savoie	2005 (amended in 2013)	+45,000 inhabitants between 1999 and 2020[6]	
PLUi Coeur des Bauges	2015 (approved in 2016)	+750 inhabitants per year up to 2030[7]	
Study area	2014 Population: 513,153 inhabitants	Harmonised data: +6,400-6,550 inhabitants per year	From 743,553 inhabitants (+230,400 inhabitants) to 748,953 inhabitants (+235,800 inhabitants)

Our projected population growth for the strategic scenario is:

[4] Page 8 of the general policy guidelines in the SCoT Arlysère
[5] Page 17 of the planning and sustainable development plan in the SCoT Bassin Annecien
[6] Page 67 of the SCoT Métropole Savoie
[7] Page 9 of the planning and sustainable development plan in the PLUi Coeur des Bauges

- Total population in 2050: 745,000 inhabitants (+232,000 inhabitants).

4.3.2 Land take

Source document	Baseline	Goal	Projection to 2050
SCoT Albanais	2004 (approved in 2005)	+600 ha in 20 years (of which +450 ha for housing)[8]	
SCoT Arlysère	2010 (approved in 2012)	+125 ha for housing in 10 years +150 ha for commercial in 20 years[9]	
SCoT Bassin Annecien	2014	Less than 1,100 ha in 20 years (of which 520 ha for housing and at least 300 ha for commercial)[10]	
SCoT Métropole Savoie	2005 (amended in 2013)	1,754 ha over 20 years[11]	
PLUi Coeur des Bauges	2015 (approved in 2016)	22-33 ha per year in new urban development up to 2030[12]	
Study area	2012 Sealed areas: 23,041 ha	Harmonised data: +215-225 ha per year	From 30,781 ha (+7,740 ha) to 31,166 ha (+8,125 ha)

Our projected land take for the strategic scenario is:

- Sealed areas in 2050: 31,000 ha;
- Land take between 2012 and 2050: +8,000 ha.

[8] Page 21 of the general policy guidelines in the SCoT Arlysère
[9] Page 9 of the general policy guidelines in the SCoT Arlysère
[10] Page 33 of the planning and sustainable development plan in the SCoT Bassin Annecien
[11] Table per commune, page 112 of the SCoT Métropole Savoie
[12] Page 19 of the planning and sustainable development plan in the PLUi Coeur des Bauges

4.3.3 Protection of natural, agricultural and forest areas

It is difficult to harmonise the content of the various strategy documents we analysed in order to define the general principles for the protection of natural, agricultural and forest areas on the scale of our study area. Accordingly, our objective here will be confined to estimating the goals set out in these documents for the protection of unsealed areas. We will use the CLC nomenclature, namely agricultural areas, forest and semi-natural areas, wetlands and water bodies.

Regarding wetlands:

Source document	**Goal**
SCoT Albanais	Protect water courses and wetlands[13] "Full protection" for the wetlands[14]
SCoT Arlysère	No damage to wetlands[15] Include the wetlands in the ecological corridors: protect and maintain continuity, ensure long-term protection of the continuity identified. Infrastructure is not banned (continuity must be restored). On an exceptional basis, a very limited urban extension may be allowed within the ecological continuity (multiple conditions).[16]
SCoT Bassin Annecien	Include the wetlands in the ecological corridors: protect, guarantee the corridors' ongoing functions. Certain developments are allowed.[17]
SCoT Métropole Savoie	Protect the wetlands[18] Protect the wetlands[19]
PLUi Coeur des Bauges	Uphold requirements concerning the quality of the water network[20]
Study area	Protect the wetlands. Urban development is banned, on principle, except under certain conditions.

Regarding agricultural areas:

Source document	**Goal**
SCoT Albanais	Protect 24,000 ha of natural and agricultural areas (for the duration of the SCoT)[21] Protect agricultural land (notion of large farm complexes) [22]

[13] Page 27 of the general policy guidelines in the SCoT Albanais
[14] Pages 16 and 45 of the general policy guidelines in the SCoT Albanais
[15] Page 12 of the general policy guidelines in the SCoT Arlysère
[16] Page 13 of the general policy guidelines in the SCoT Arlysère
[17] Page 10 of the planning and sustainable development plan in the SCoT Bassin Annecien
[18] Page 59 of the SCoT Métropole Savoie
[19] Page 97 of the SCoT Métropole Savoie
[20] Page 15 of the planning and sustainable development plan in the PLUi Coeur des Bauges
[21] Page 27 of the general policy guidelines in the SCoT Albanais
[22] Page 32 of the general policy guidelines in the SCoT Albanais

SCoT Arlysère	Principle of balancing development and protection of natural and agricultural areas[23] Natural and agricultural areas are not available for urban development (identification of the agricultural areas to be maintained; on an exceptional basis, developments authorised under certain conditions)[24]
SCoT Bassin Annecien	Protect agricultural land[25] Protect agricultural areas of major importance[26] Protect ordinary agricultural areas as long as possible[27]
SCoT Métropole Savoie	Protect agriculture[28] Appropriate sizing of the local planning regulations helps protect agricultural land[29] Certain agricultural areas of major importance can be given more specific protection[30]
PLUi Coeur des Bauges	Protect agricultural land[31] Establish a sustainable future for agriculture and forestry (maintain and develop the industry)[32]
Study area	Given that these agricultural areas occupy a large proportion of the local communes, even if a general protection principle is applied by all of them, the majority of the land take will be from the agricultural areas. On principle, agricultural areas contained within ecological continuities are maintained and, for this reason, they enjoy a high level of protection. Most of the documents provide for important agricultural areas to be identified, or identify them themselves. The level of protection of these areas is generally tightened. *It was not possible to identify these areas for the study area as a whole.* For the other agricultural areas, the principles laid down tend to maintain and protect farming (and not compromise farms).

Regarding forest areas:

Source document	Goal
SCoT Albanais	Full or strict protection of large forest tracts[33]
SCoT Arlysère	

[23] Page 9 of the general policy guidelines in the SCoT Arlysère
[24] Pages 11 and 19 of the general policy guidelines in the SCoT Arlysère
[25] Page 6 of the planning and sustainable development plan in the SCoT Bassin Annecien
[26] Page 17 of the planning and sustainable development plan in the SCoT Bassin Annecien
[27] Page 19 of the planning and sustainable development plan in the SCoT Bassin Annecien
[28] Page 59 of the SCoT Métropole Savoie
[29] Page 113 of the SCoT Métropole Savoie
[30] Page 121 of the SCoT Métropole Savoie
[31] Page 19 of the planning and sustainable development plan in the PLUi Coeur des Bauges
[32] Page 21 of the planning and sustainable development plan in the PLUi Coeur des Bauges
[33] Pages 15 and 29 of the general policy guidelines in the SCoT Albanais

SCoT Bassin Annecien	Protect the forestry industry[34] Protect (under the French Loi Littoral coastal protection law) forests identified as outstanding areas [35]
SCoT Métropole Savoie	
PLUi Coeur des Bauges	Establish a sustainable future for agriculture and forestry (maintain and develop the industry)[36]
Study area	SCoT documents contain information about forestry and the use of wood for energy. However, apart from these aspects, the documents we analysed do not always address the issue of protecting forest areas. On principle, forest areas contained within ecological continuities are maintained and, for this reason, they enjoy a high level of protection. Certain documents, in particular those subject to the Loi Littoral, provide for the protection of large forest tracts.

[34] Page 60 of the planning and sustainable development plan in the SCoT Bassin Annecien
[35] Page 64 of the planning and sustainable development plan in the SCoT Bassin Annecien
[36] Page 21 of the planning and sustainable development plan in the PLUi Coeur des Bauges

4.4 Applications of the baseline and strategic scenarios in the modelling software programs

4.4.1 To construct the attractiveness map

To produce the attractiveness map without using the dedicated module available in the FORESIGHT software, we began by designing a "friction" map. Using the friction map, we assigned a value to each pixel in the area, based on our estimate of its permeability to urban development: the existing urban development pixels had the lowest friction values, while other areas (in particular water bodies) had a maximum value.

For the baseline scenario, the attractiveness of the various urbanised areas was adjusted according to the recent demographic trends (between 2009 and 2014). For the unsealed areas, the friction factors were adjusted in accordance with the pace of land take observed between 2000 and 2012. The vast majority of the land take occurs from agricultural and forest areas, with a smaller percentage from wetlands. Accordingly, we assigned a coefficient to each of these areas, while at the same time processing certain more specific land uses separately. Examples include permanent crops, which display virtually no change in our study areas, or bare rocks and glaciers, which do not change over time.

For the strategic scenario, the attractiveness of the various urbanised areas was adjusted in accordance with the regional framework defined in the area's strategy documents. At the same time, we agreed on a way to harmonise the level of the various main centres across our study area. For the friction factor of the unsealed areas, we adopted the following principles, while harmonising the information collected in our study areas:

- Major reinforcement of the protection of wet lands;
- Reinforcement of the protection of agricultural areas;
- No change in forest areas' friction factor: these areas are naturally better protected from the phenomenon of land take and there is little discussion of them in strategy documents, apart from biodiversity protection issues *(Trames vertes et bleues),* so we decided not to change the forest areas' friction factor.

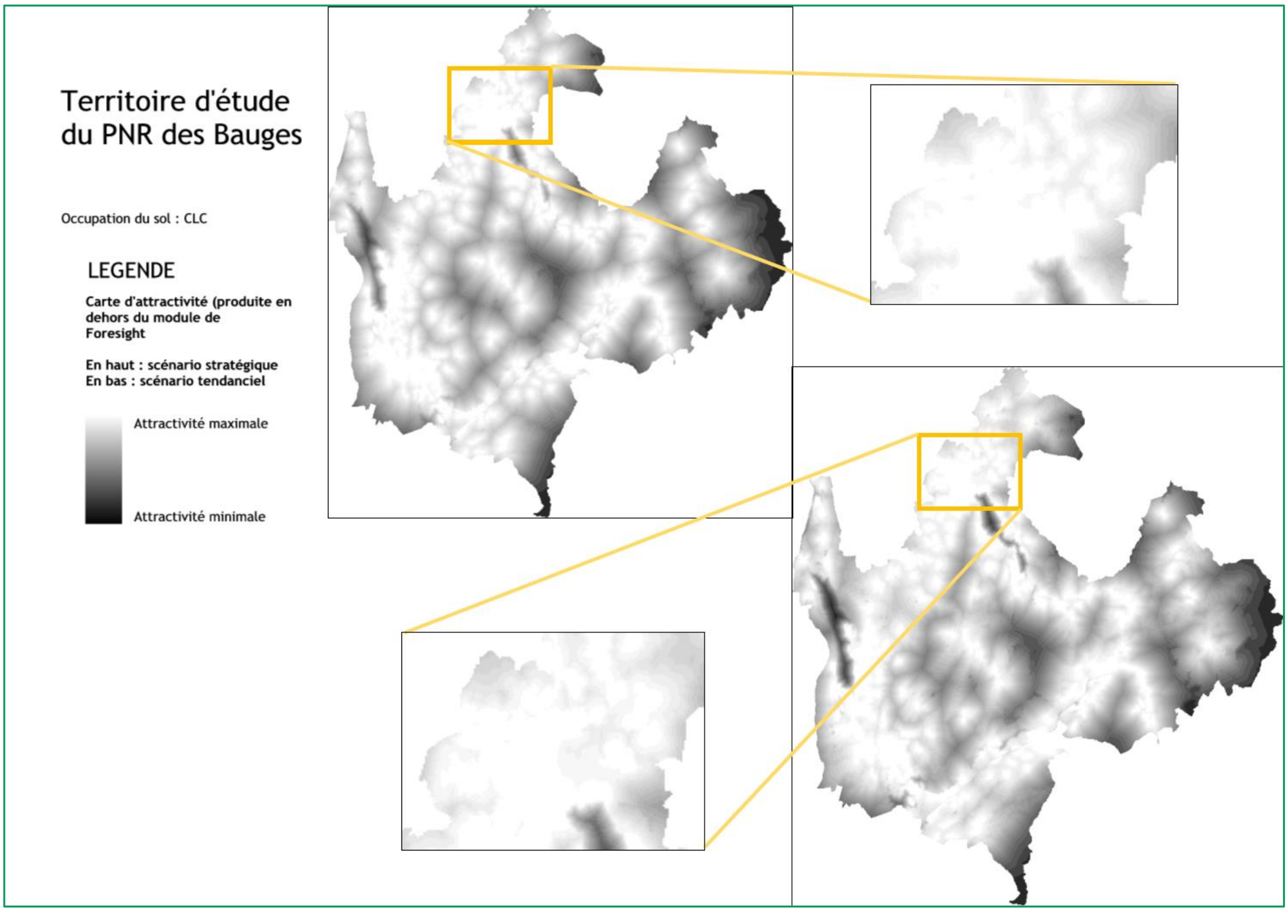

Figure 15: Attractiveness maps produced outside the dedicated FORESIGHT module for the Bauges Regional Nature Park study area and for the strategic and baseline scenarios (zoomed images)

4.4.2 For FORESIGHT

To test the baseline and strategic scenarios in different situations, we also planned to vary two other parameters available in FORESIGHT:

- Land take:
  - This was set at 7,000 ha for the baseline scenario and 8,000 ha for the strategic scenario
- The urban sprawl patterns:
  - For the baseline scenario, the values set were based on an analysis of changes in the urban footprint between 2009 and 2017[37]
    - Spontaneous: 5
    - New Spread Center: 8
    - Road Influenced: 18
    - Edge-Growth: 69

[37] See the methodology report

- For the strategic scenario, urban scattering and linear sprawl are greatly reduced.
  - Spontaneous: 0
  - New Spread Center: 2
  - Road Influenced: 8
  - Edge-Growth: 90.

4.4.3 For LUCSIM

To test the baseline and strategic scenarios in different situations in LUCSIM, we following the study programme: we used the software in "fully automatic" mode to model the baseline scenario, applying only Markov chain constraints to the modelling process to limit urban development to around 7,000 ha.

To test the strategic scenario, we also used Markov chains to limit urban development to around 8,000 ha. We also used the strategic scenario's attractiveness map as both additional information in the decision tree and a Potential Model constraint.

Since we were unsure of how our attractiveness map would influence the outcome, we also ran a series of modelling processes using LUCSIM's built-in potential model. To calculate the potential model, a weight is assigned to each type of land use: the higher the weight, the greater the attractiveness.

We used the following weights:

Continuous urban fabric	100	Discontinuous urban fabric	95	Industrial and commercial zones	10
Other sealed areas	20	Agricultural areas	80	Permanent crops	20
Forest areas	70	Bare rocks and glaciers	0	Wetlands	1
Water	0				

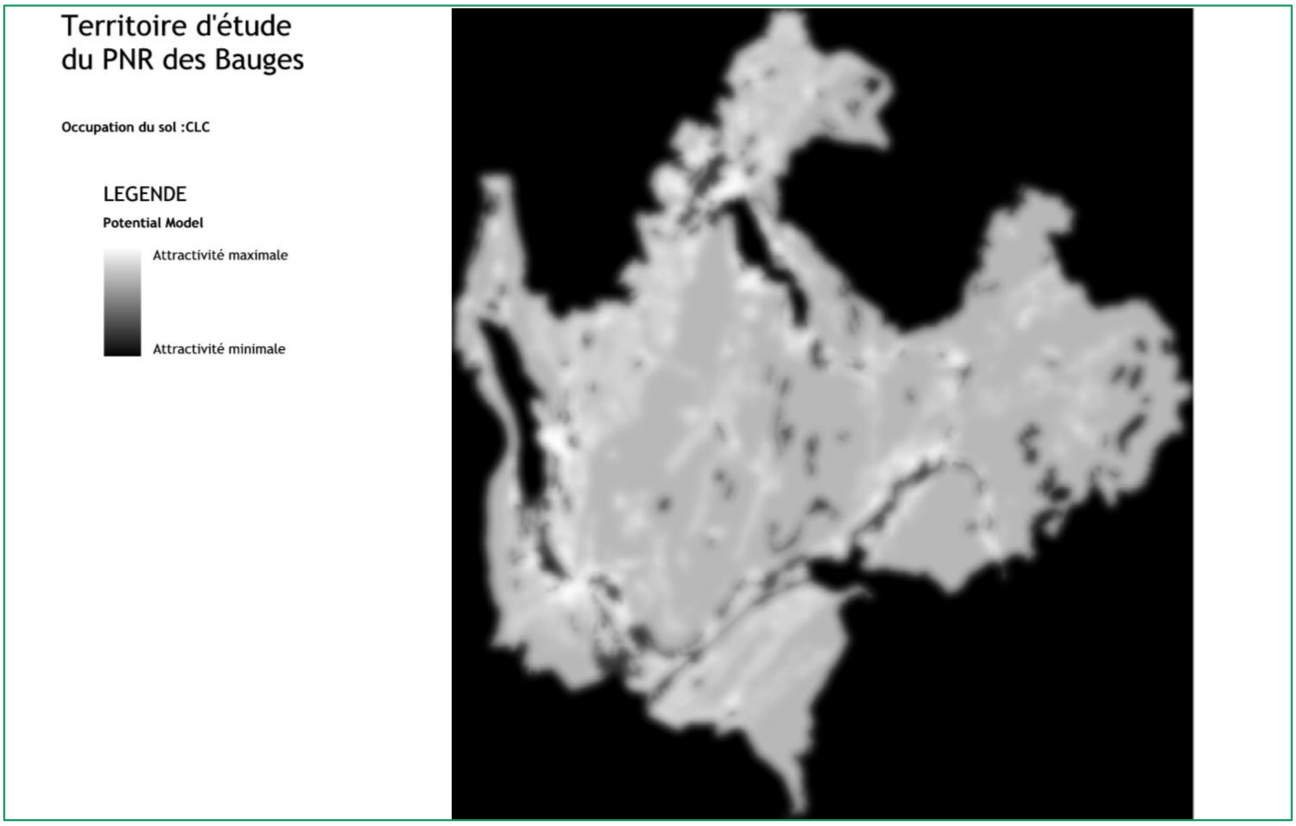

Figure 16: Potential model for the Bauges Regional Nature Park study area

5 Results and analysis – "What we managed to do"»

5.1 Feedback

More detailed feedback is given in the methodology report.

5.1.1 Leveraging the attractiveness map

Once the attractiveness maps had been produced for each of our scenarios, we were able to incorporate them without difficulty into LUCSIM. However, the fact that the models were generated at the very end of the assignment did not leave us time to really step back for an objective assessment of their impact on modelling.

With FORESIGHT, on the other hand, we were unable to incorporate our attractiveness maps into the modelling process (the data was not recognised)[38]. We accordingly adjusted our methodology and managed, despite it all, to produce an attractiveness map, this time using the dedicated FORESIGHT module. Thanks to that, we were able to continue our testing of the FORESIGHT software.

[38] After further testing, we were able to incorporate one of our attractiveness maps into FORESIGHT. There is no way to do this through the *Pre-processing* tab. However, it was possible to generate the *.gif file for one of our attractiveness maps directly through ArcGIS. Users will need to ensure that the resolution and extent are strictly identical to those in the files generated by FORESIGHT in the *Input* folder for the *Initial Urban Map* data, for example. The file was then copied into a model's *Input* folder, where it was recognised by the software *(Preview* in the *Initial settings* tab*)*, then used to generate a model based on our own attractiveness map.

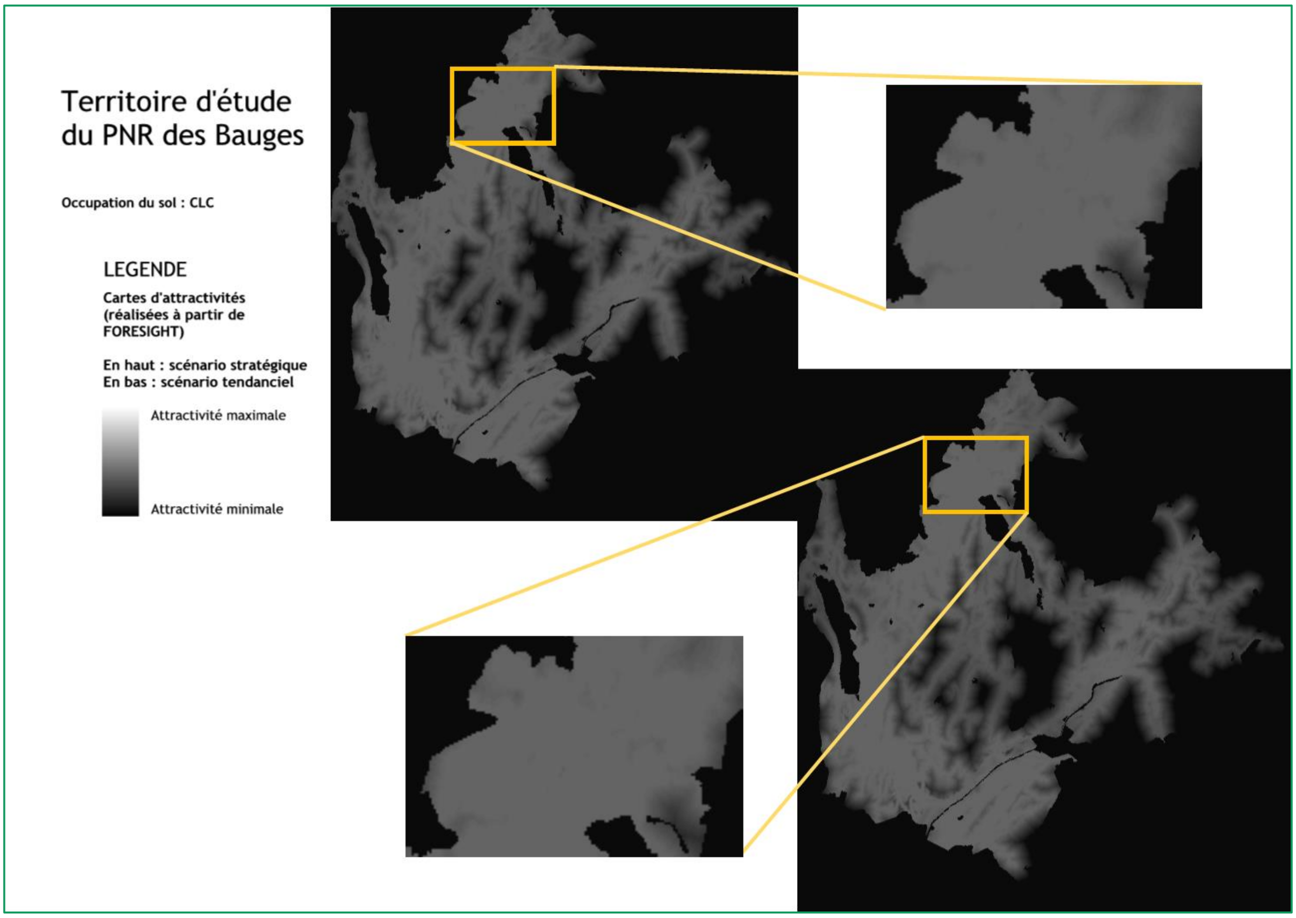

Figure 17: Attractiveness maps produced with FORESIGHT for the Bauges Regional Nature Park study area and for the strategic and baseline scenarios (zoomed images)

5.1.2 Testing with FORESIGHT

5.1.2.1 The modelling processes

For our study area, for each of the two databases we used to define the Initial Urban Map (CLC and OSCOM) and for each of our two "Baseline" and "Strategic" scenarios, we produced the following:

- A single model of the study area as a whole;
- A series of 20 models;
- A map of the probability of urban development for each scenario, based on the Future uncertainty option and using the 20 models produced earlier.

5.1.2.1.1 Based on CLC data

The urban development created by FORESIGHT covers 7,000 ha for the baseline scenario and 8,000 ha for the strategic scenario.[39]

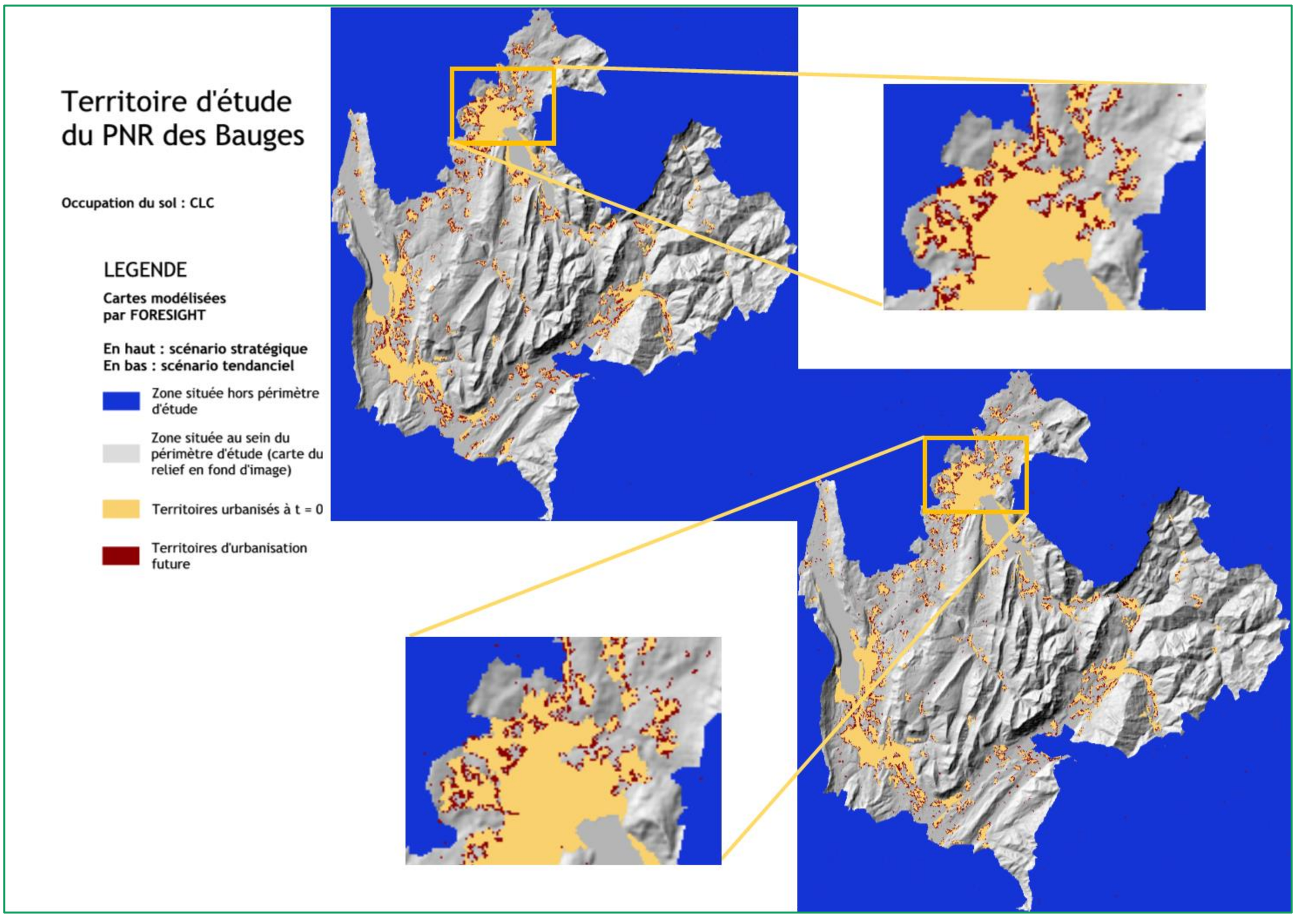

Figure 18: Models obtained for the Bauges Regional Nature Park study area using CLC data and for the strategic and baseline scenarios

[39] An explanation of the values used can be found in the two reports on the study areas.

The probability maps were obtained from 20 models produced for each of our scenarios.

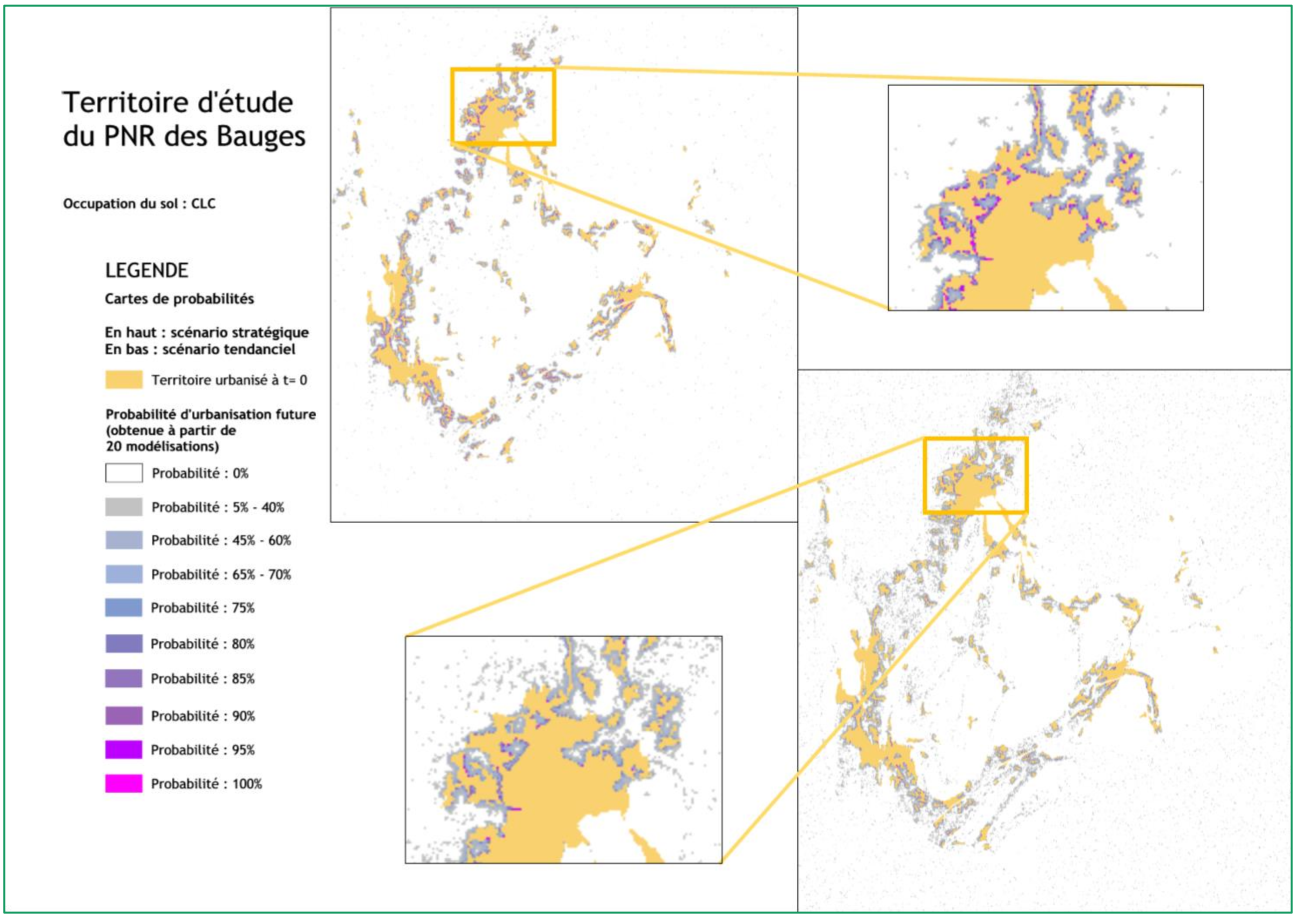

Figure 19: Urban development probabilities based on 20 models of the Bauges Regional Nature Park study area using CLC data and for the strategic and baseline scenarios

5.1.2.1.2 Based on OSCOM data

The results obtained with the OSCOM data are shown below.

The urban development created by FORESIGHT covers 7,000 ha for the baseline scenario and 8,000 ha for the strategic scenario.[40]

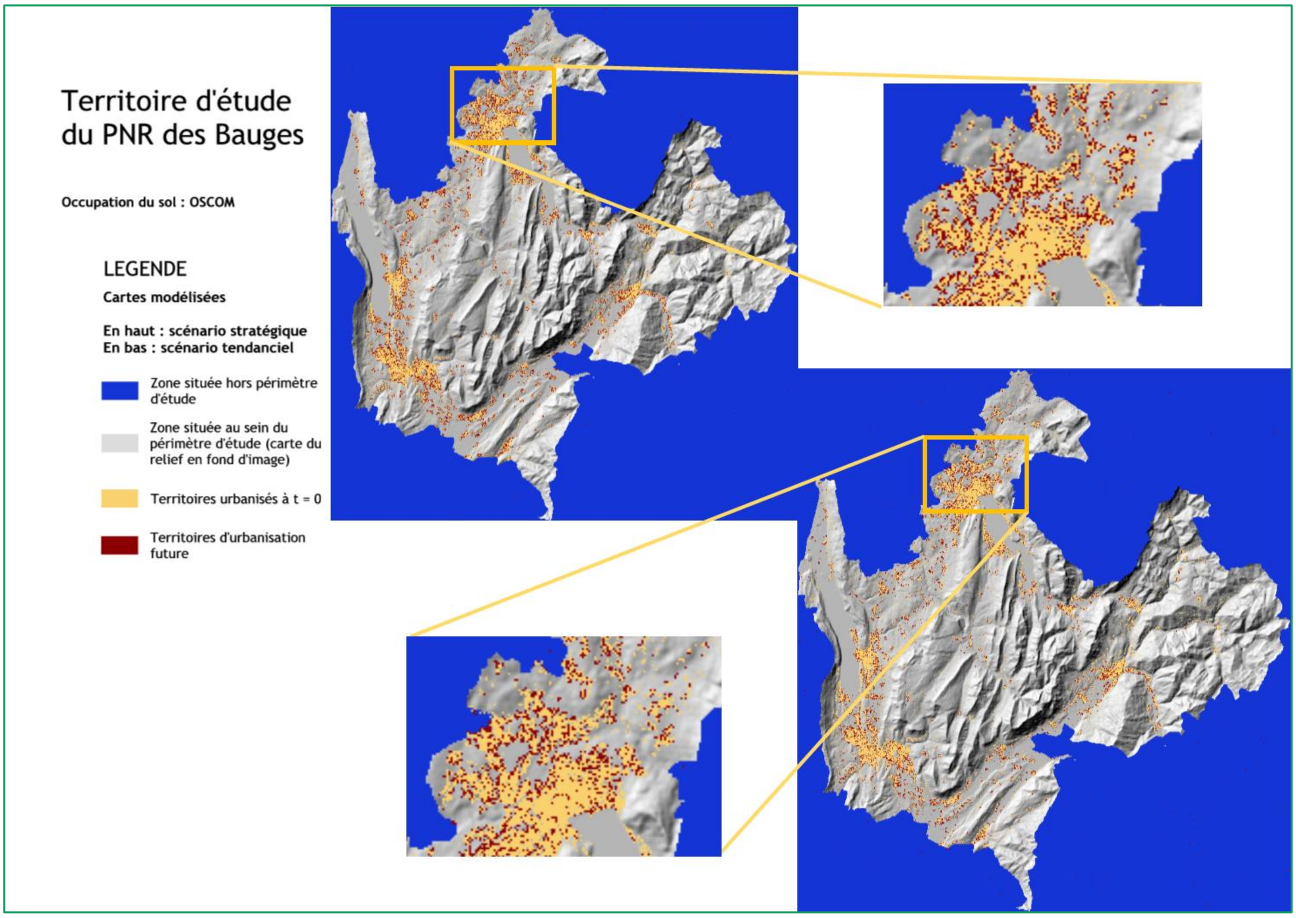

Figure 20: Models obtained for the Bauges Regional Nature Park study area using OSCOM data and for the strategic and baseline scenarios

[40] An explanation of the values used can be found in the two reports on the study areas.

The probability maps were obtained from 20 models produced for each of our scenarios.

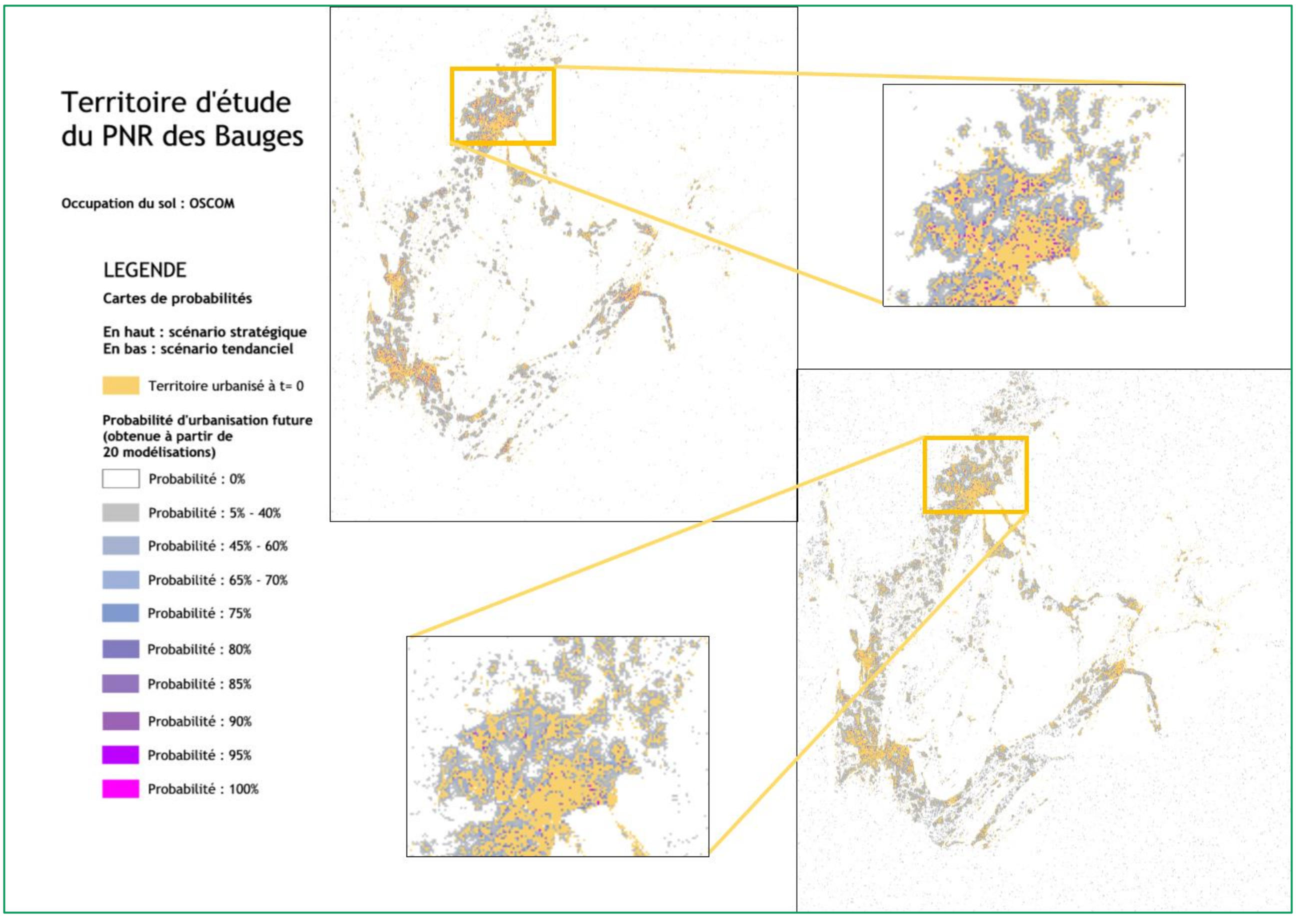

Figure 21: Urban development probabilities based on 20 models of the Bauges Regional Nature Park study area using OSCOM data and for the strategic and baseline scenarios

5.1.2.2 Analysis of the modelled maps

Our testing of the software yielded two types of output from FORESIGHT:

- The map of the new urban development;
- The probability map.

Each of these maps, in *.gif format, must be georeferenced so that it can be incorporated into a GIS software program. Our analytical strategy is then to count the different types of pixel, which do not have the same meaning, depending on the different maps produced.

To be able to compare each scenario's impact on the models produced by FORESIGHT, our analytical strategy also entails analysing the various maps from two regional viewpoints:

- Based on the breakdown into public inter-municipal cooperation establishments (EPCIs);
- Based on the area's development framework, defined on the basis of an analysis of the area's strategy documents).

Our objectives are to confirm the differences between our scenarios with regard to land take and the way the area is developed, proof that changing the Patterns does indeed have an impact on the models.

In the Bauges Regional Nature Park study area, the maps are modelled with CLC and OSCOM data. Our objective is to analyse the results obtained in order to see how the data source influences the models.

The analysis performed according to the area's development framework is aimed at confirming the impact of the attractiveness maps on the preferred location of the new urban development pixels in the area.

Any other regional breakdown could have been used to carry out this analysis. While there would be little point in analysing the exact location (a specific land parcel, for example) of the pixels generated by FORESIGHT, an analysis by geographical sector is far more meaningful. Repeating the modelling processes will also enhance the quality of the information gathered.

5.1.2.3 Analysis of the probability maps

The probability maps provide additional information not contained in the modelled maps. By enabling us to identify sectors in which the probabilities of urban development are very high for a given scenario, they provide a far more macroscopic approach than with a map simply modelled by FORESIGHT. Probability maps also make it easier to see urbanisation trends, whether linear development or the agglomeration of several developed areas (gradually filling in certain vacant spaces).

For all of these reasons, these maps would be worth analysing in greater detail than we were able to do, because we used the same type of processing for these maps as for the modelled maps.

This analysis nevertheless confirms certain outcomes:

- The influence of the Patterns: the Spontaneous and New spread center parameters are typically random phenomena whose effects on urban development are not systematic. In the probability map, this is reflected in a proliferation of pixels with relatively low probabilities of urban development. The Edge growth parameter, on the other hand, will systematically develop the perimeter of all of the entities initially developed, in all of the models. In fact, we will be able to see very high probabilities of development in the immediately adjacent areas.
- The influence of the databases: in the Bauges Regional Nature Park study area, we can see that the initial urban development defined with OSCOM differs to that defined with CLC, particularly in the way the area is divided up. Where CLC yielded extensive areas of urban development, we have far more precisely defined developed areas with OSCOM (despite using a 100 m square minimum mapping unit). Moreover, in some sectors with sparse development, OSCOM identifies developed areas that CLC failed to register. Even if no detailed analysis of these differences was undertaken during the current testing, we can suppose that this degree of precision in the information had an impact on the modelling, since the Edge growth parameter is directly influenced by these differences.

5.1.3 Testing with LUCSIM

5.1.3.1 Using the CLC database

For each of our study areas, we were able to incorporate the 2000 and 2012 editions of CLC using a simplified nomenclature consisting of 10 items.

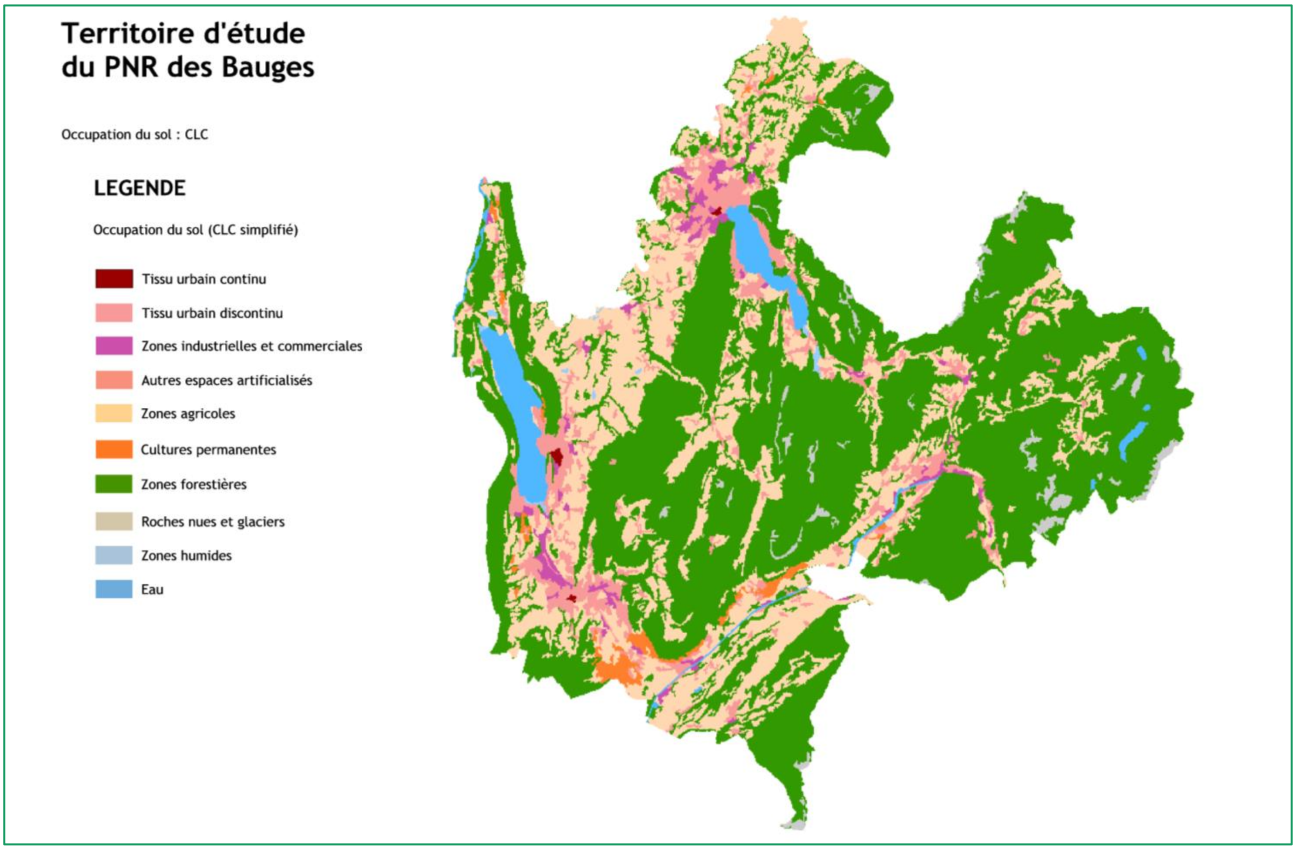

Figure 22: Land use (simplified CLC data) in the Bauges Regional Nature Park study area in 2012

The Continuous urban fabric land use category is very uncommon in our study areas, so we decided not to include it in the model. Instead, we focused solely on the land use category Discontinuous urban fabric.

In accordance with the planned study programme, we carried out three series of modelling processes:

- With neither an attractiveness map nor a potential model;
- With a potential model calculated by LUCSIM, incorporated into both the decision tree and the constraints;
- With the attractiveness map we produced for the strategic scenario, incorporated into both the decision tree and the constraints.

For each model, we also applied a Markov chain constraint):

- As mentioned in the description of the LUCSIM software's operation, a Markov chain takes the form of a transition matrix, which we can subsequently raise to the desired power. By multiplying this transition matrix with the initial land use (in matrix form), we obtain a theoretical quantity of each final land use. This calculation applies the following principle: if we repeated the past trends X times

(X being the value of the transition matrix power), what would be the new quantities of the various types of land use in our study area?

- Focusing solely on the Discontinuous urban fabric, we used the power values that would produce a quantity of created pixels (≈ land take) equivalent to the land take calculated for our strategic and baseline scenarios. For the series of modelling processes with neither an attractiveness map nor a potential model, we used the land take data for the baseline scenario. For the other series of modelling processes, we used the data for the strategic scenario.

For each situation, we went through the decision tree three or four times, varying the size of the learning sector in the tree (Neighborhood radius parameters).

From the set of transition rules obtained, we retained for the modelling process only those that did not explicitly change the following types of land use: Water, Wetlands, Continuous urban fabrics, Industrial and commercial zones, Other sealed areas, because we believed that these rules would produce unwanted effects.

5.1.3.2 Dramatic increase in the computational time for analysing the HRL and Theïa databases

When we were testing LUCSIM with the other databases, we ran into a problem: the time taken to run the decision tree using Theïa and HRL data increased dramatically. When we used CLC data, the run time was about half an hour. For HRL and Theïa alike, we stopped the process after two days without having obtained any results.

This situation is largely due to the level of precision of the initial data (size of the minimum mapping unit and precision of the nomenclature). The minimum mapping unit is much smaller for the latter two databases than for the CLC data, making it more complicated to run the decision tree's algorithm.

Next steps

Given the longer run times, which compromise the use of these databases for modelling, and to reduce computational time, possible solutions could be to:

- Simplify learning within the decision tree:
    - Reduce the share of learning: within the decision tree, the Training ratio, set by default at 75/100, indicates the proportion of pixels with which the decision tree determines the transition rules. Lowering this ratio should make it possible to reduce the computational time, though we cannot be sure of this.
    - Reduce the learning sector: by adjusting the *Neighborhood Radius* parameters within the decision tree, i.e. the parameter used to set the sector around each pixel studied by the decision tree to determine the transition rules, it is possible to reduce the learning sector and, in so doing, shorten the computational time. For example, reducing the radius from 10 to 8 will approximately halve the quantity of pixels in each sector analysed by the algorithm.
    - Do not use the *Weight* option: this option can be used to overvalue the changes in order to make the rules more accurate. However, it also makes the decision tree algorithm more complex, which may affect computational time.
- Simplify the input data:
    - Reduce the number of classes.
    - Reduce the precision of the information: HRL is available with 20 metre square pixels and Theïa with 30 metre square pixels. One way of reducing processing time would be to use larger-sized pixels, up to 100 metre square, which would yield a level of precision comparable to that of CLC. However, it should be borne in mind that this has the direct result of reducing information precision.

In view of these considerations, we decided to apply some of these solutions to the HRL data and the Thonon Conurbation study area. With the HRL data, the changes observed between 2006 and 2015 are significantly greater in the Thonon Conurbation study area than in the Bauges Regional Nature Park study area (negligible changes). We therefore decided to confine our last processing operations to the Thonon Conurbation study area.

5.1.3.3 Modelling the Thonon Conurbation study area with HRL data

To simplify the input data, we reduced the level of precision of the HRL data by increasing the pixel size (to 100 metres square). Based on our two layers, 2006 and 2015, we were then able to obtain concrete results in defining rules with the decision tree. The decision tree was applied to all of the different types of land use so that we could generate changes for each of them.

For want of time, we did not run modelling operations constrained by the potential model or an attractiveness map. Given that we intended to change different types of land use concomitantly, it was effectually impossible to apply a constraint such as a Markov chain. Even if the Markov chain indicates changes for each type of land use, these changes will not necessarily be carried out through the application of our transition rules. As we saw from experience, during the modelling process it is quite possible to have a type of land use that increases significantly whereas the other types are stable or even diminish, since this depends directly on the rules applied

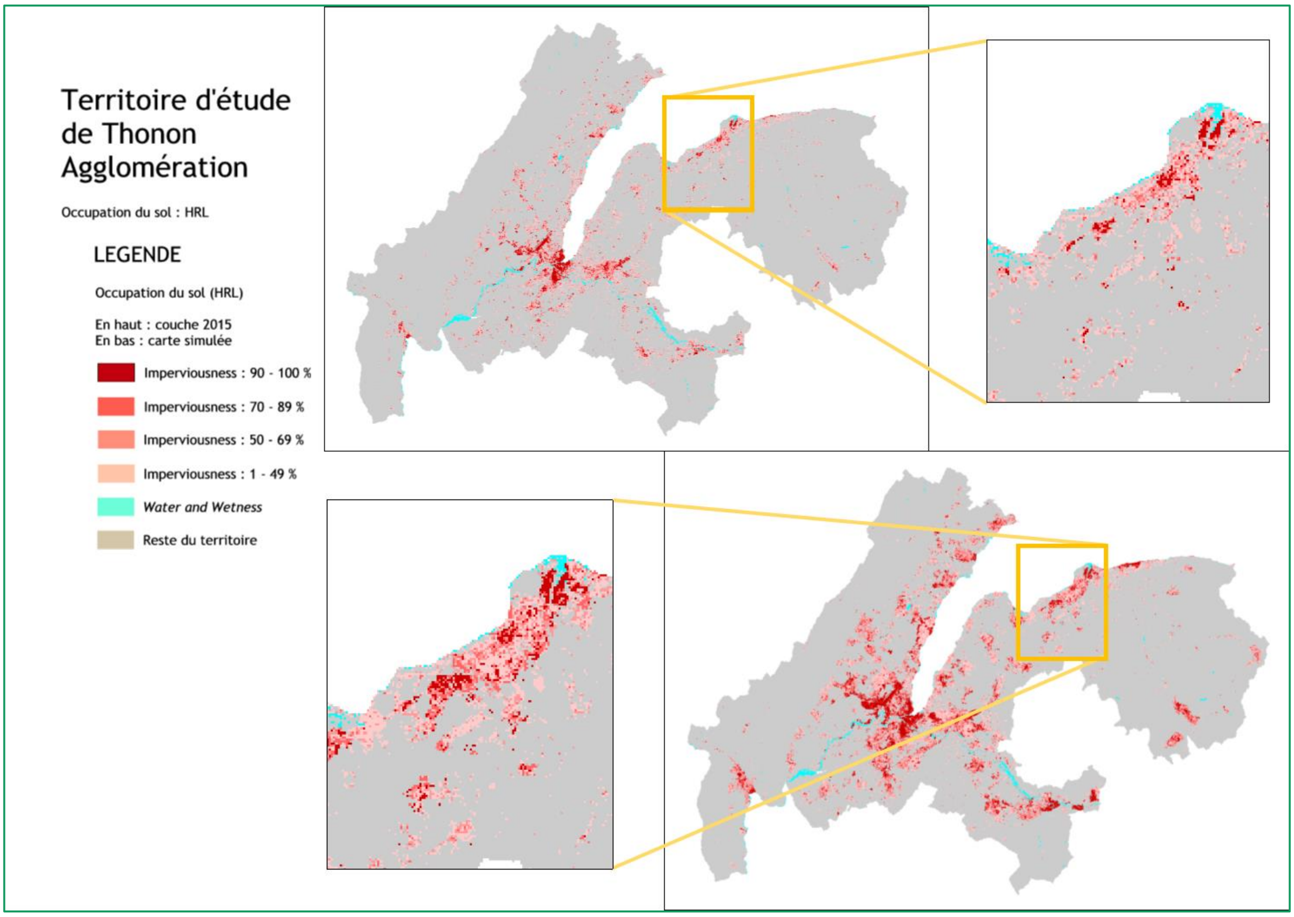

Figure 23: Model of the Thonon Conurbation study area obtained using LUCSIM and the HRL database

5.1.3.4 Analysis of the results and feedback

For want of time, we were unable to develop any real strategy for analysing the results obtained from LUSCIM.

5.2 Analysis of the results obtained from FORESIGHT

All of the mapping results have been presented above.

5.2.1 Visual analysis

A visual analysis of the modelled maps pinpoints differences between our two scenarios.

The land take parameter is not sufficiently different in the two scenarios used for the Bauges Regional Nature Park study area for it to have a significant effect on their respective models.

However, it is much easier to gauge the impact of the differences between our two scenarios on the urban sprawl patterns generated:

- The strategic scenario favours an edge-growth pattern of urbanisation, while the baseline scenario generates more pronounced urban scattering and linear growth. Visually, it results in more concentrated urbanisation with the strategic scenario and more dispersed urbanisation with the baseline scenario.

With visual analysis alone, though, it is virtually impossible to verify the impact of our attractiveness maps (presented above) on the location of urban development.

5.2.2 Analysis by public inter-municipal cooperation establishment (EPCI)

To complement this initial visual analysis, we analysed a breakdown of the results into the study area's constituent EPCIs (see below). For our first analysis, we divided up the study area by EPCI and added the area comprising the Bauges Regional Nature Park. For these different areas, as well as the total surface area of the study area, we counted all of the pixels created by FORESIGHT: first using a model, then the aggregate data for 20 models and of course for our two databases and our two change scenarios.

5.2.2.1 For one model

	CLC 2050			
Territoire PNR BAUGES	**Stratégique**		**Tendanciel**	
CC des Sources du Lac d'Annecy	393	4,96 %	348	5,19 %
CC Coeur de Savoie	1241	15,65 %	1058	15,79 %
CA du Lac du Bourget (Grand Lac)	1208	15,23 %	1045	15,59 %
CA du Grand Annecy	2672	33,69 %	2165	32,31 %
CA Chambéry Métropole-Coeur des Bauges	1306	16,47 %	1172	17,49 %
CA Arlysére	1110	14,00 %	913	13,62 %
PNR des Bauges	1712	21,59 %	1479	22,07 %
Grand territoire d'étude	7930	100,00 %	6701	100,00 %
Pixels créés en dehors du périmètre d'étude	77		287	
Somme des pixels créés	8007		6988	

Table 1: Number of pixels (and proportion of the total) created per EPCI for each scenario, based on CLC data

Territoire PNR BAUGES	OSCOM 2050			
	Stratégique		Tendanciel	
CC des Sources du Lac d'Annecy	329	4,14 %	271	4,04 %
CC Coeur de Savoie	1079	13,59 %	896	13,35 %
CA du Lac du Bourget (Grand Lac)	1253	15,78 %	1104	16,45 %
CA du Grand Annecy	2818	35,48 %	2361	35,17 %
CA Chambéry Métropole-Coeur des Bauges	1533	19,30 %	1300	19,37 %
CA Arlysére	930	11,71 %	781	11,63 %
PNR des Bauges	1605	20,21 %	1310	19,51 %
Grand territoire d'étude	7942	100,00 %	6713	100,00 %
Pixels créés en dehors du périmètre d'étude	134		76	
Somme des pixels créés	8076		6789	

Table 2: Number of pixels (and proportion of the total) created per EPCI for each scenario, based on OSCOM data

This initial analysis highlights a first effect, namely the distinctions made between our two scenarios.

- Using the CLC data, the distribution of the pixels created according to the scenarios is different: the proportion of pixels created in the Communauté d'Agglomération du Grand Annecy and, to a lesser extent, in the Communauté d'Agglomération Arlysère is higher in the strategic scenario than in the baseline scenario. The opposite can be seen in the Communauté d'Agglomération Chambéry Métropole-Coeur des Bauges and the Bauges Regional Nature Park.
- Using the OSCOM data, the distribution of the pixels created according to the scenarios is different: the proportion of pixels created in the Communauté d'Agglomération du Grand Annecy and in the Bauges Regional Nature Park is higher in the strategic scenario than in the baseline scenario. The opposite can be seen in the Communauté d'Agglomération du Lac du Bourget.

This initial analysis, carried out on a model, seems to differentiate the strategic and baseline scenarios with respect to the distribution of urban sprawl by EPCI.

- The only way to confirm this result would be to repeat the analysis on a number of models.

This initial analysis also highlights another effect: the impact of the database used on the results obtained.

- For a given scenario, the results obtained for CLC and OSCOM differ, but always in the same way. The differences between the results for each of the databases are always similar, whatever the scenario. For example, the quantity and proportion of pixels created with OSCOM is always higher than with the same data from CLC, in the CA du Grand Annecy, the CA de Chambery Métropole-Coeur-des-Bauges and the CA du Lac du Bourget. The opposite result is obtained in the other EPCIs in the area and the Bauges Regional Nature Park.
- This effect merits a more detailed, in-depth analysis. An initial hypothesis is that this phenomenon is due to the distribution of information in the area, which is not the same for CLC and OSCOM.

Note that, during the modelling processes carried out, we did not explicitly exclude areas outside our study area. This explains why the software created a certain number of pixels outside the study area. The effect is far more pronounced for the baseline scenario, for the simple reason that there is more dispersion and urban scattering for this latter scenario.

5.2.2.2 Based on 20 models

Territoire BAUGES	CLC 2050 Stratégique				CLC 2050 Tendanciel			
	1	2	3	4	1	2	3	4
Nb pixels pour une probabilité	**<25**	**25-50**	**50-75**	**75-100**	**<25**	**25-50**	**50-75**	**75-100**
CC des Sources du Lac d'Annecy	442	223	240	142	706	237	205	41
CC Coeur de Savoie	1893	572	626	498	4154	607	533	234
CA du Lac du Bourget (Grand Lac)	1650	643	646	454	3386	666	584	155
CA du Grand Annecy	3053	1241	1363	1033	6161	1300	1226	423
CA Chambéry Métropole-Coeur des Bauges	1591	665	679	467	3394	675	594	191
CA Arlysére	1183	585	573	456	4154	607	533	234
PNR des Bauges	2715	983	910	487	5796	984	733	178
Grand territoire d'étude	10878	3932	4138	3050	26016	4084	3659	1216
Proportion	49,45 %	17,87 %	18,81 %	13,86 %	74,38 %	11,68 %	10,46 %	3,48 %

Table 3: *Number of pixels, based on their value per EPCI, for each scenario and for the CLC database*

Territoire BAUGES	OSCOM 2050 Stratégique				OSCOM 2050 Tendanciel			
	1	2	3	4	1	2	3	4
Nb pixels pour une probabilité	**<25**	**25-50**	**50-75**	**75-100**	**<25**	**25-50**	**50-75**	**75-100**
CC des Sources du Lac d'Annecy	651	293	177	30	901	257	96	8
CC Coeur de Savoie	2403	765	451	135	4573	680	322	42
CA du Lac du Bourget (Grand Lac)	2263	876	642	266	4001	817	486	96
CA du Grand Annecy	4458	1925	1599	650	7043	1773	1236	232
CA Chambéry Métropole-Coeur des Bauges	2301	957	746	513	3784	922	674	210
CA Arlysére	1661	732	497	237	2520	635	404	84
PNR des Bauges	3736	1295	718	183	6430	1110	450	43
Grand territoire d'étude	14747	5557	4119	1834	28652	5096	3223	672
Proportion	56,16 %	21,16 %	15,69 %	6,98 %	76,12 %	13,54 %	8,56 %	1,79 %

Table 4: *Number of pixels, based on their value per EPCI, for each scenario and for the CLC database*

These maps, which are far more complex to analyse, help corroborate certain effects.

5.2.2.2.1 Comparison of the results for the two scenarios

This clearly brings out the differences between the strategic and baseline scenarios. The proportion of pixels that are highly likely to be developed is markedly higher for the strategic scenario than for the baseline scenario. This observation is directly attributable to the distinction made between the two scenarios by the Patterns. The strategic scenario favours edge growth and drastically curbs urban scattering. This inevitably results in reproducing a similar pattern of urban development from one model to another, thereby increasing the quantity of pixels with high probabilities for the strategic scenario.

5.2.2.2.2 Comparison of the results for the two databases

As already mentioned, the OSCOM data shows more scattering in the area and therefore generates more differences between each model. In the probability map, this results in a lower proportion of pixels with high probabilities for the OSCOM data than for the CLC data.

5.2.3 Analysis based on the urban framework

For our second analysis, we divided up the study area along the lines of its urban framework.

Note that we have used identical terminology for the different levels of importance and attraction in our two study areas, based on the terminology used for the Geneva area.

Note also that, for this second analysis, we worked with simulation maps only, without studying the probability maps.

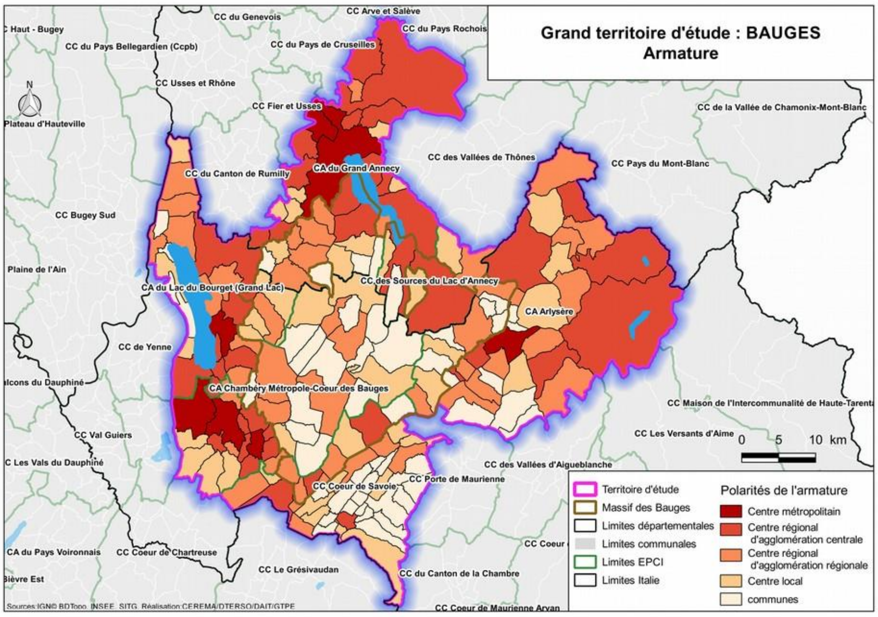

Figure 24: Urban framework of the study area (Cerema nomenclature, identical for both study areas)

Territoire PNR BAUGES	CLC 2050			
	Stratégique		**Tendanciel**	
Centres métropolitains	1377	17,36 %	1152	17,19 %
Centres régionaux d'agglomération centrale	2972	37,48 %	2479	36,99 %
Centres régionaux	2052	25,88 %	1702	25,40 %
Centres locaux	1170	14,75 %	995	14,85 %
Autres communes	359	4,53 %	375	5,60 %
Grand territoire d'étude	7930	100,00 %	6701	100,00 %
Pixels créés en dehors du périmètre d'étude	77		287	
Somme des pixels créés	8007		6988	

Table 5: Number and proportion of pixels created for each level of the urban framework and for each scenario, based on CLC data

Territoire PNR BAUGES	OSCOM 2050 Stratégique		OSCOM 2050 Tendanciel	
Centres métropolitains	2188	27,55 %	1871	27,87 %
Centres régionaux d'agglomération centrale	3123	39,32 %	2555	38,06 %
Centres régionaux	1481	18,65 %	1270	18,92 %
Centres locaux	814	10,25 %	735	10,95 %
Autres communes	336	4,23 %	282	4,20 %
Grand territoire d'étude	7942	100,00 %	6713	100,00 %
Pixels créés en dehors du périmètre d'étude	60		292	
Somme des pixels créés	8002		7005	

Table 6: Number and proportion of pixels created for each level of the urban framework and for each scenario, based on OSCOM data

This second analysis highlights an initial effect, namely the distinctions made between our two scenarios.

- Using the CLC data, the distribution of the pixels created according to the scenarios is different: the proportion of pixels created at the first four levels of the area's main centres is significantly higher in the strategic scenario than in the baseline scenario. The difference is more marked on level 2 (regional centres with a central agglomeration).
- Using the OSCOM data, the distribution of the pixels created according to the scenarios is different: the proportion of pixels created at level 2 is higher in the strategic scenario than in the baseline scenario. At all of the other levels of regional importance, the reverse is true.

This second analysis, based on a model, seems to differentiate between strategic and baseline scenarios with respect to the distribution of urban sprawl according to the area's urban framework, so highlights the role of the attractiveness map. The concentration around main centres in the strategic scenario is mainly evident for level 2 (Regional centres of central agglomeration).

- The only way to confirm this result would be to repeat the analysis on a number of models.

Like the first analysis, this second analysis reflects the impact of the source database on the modelling process:

- For a given scenario, the results obtained with CLCL and OSCOM data differ. The quantity and proportion of pixels created with OSCOM is consistently greater that with the same data sourced from CLC, for the first two levels of polarity. For the other levels of polarity and the other communes, the result is the opposite.

5.2.4 Summary of the analysis

The analysis of the Bauges Regional Nature Park study area confirms that the choices we made to distinguish our two scenarios for the area's future development have a significant impact. For the land take and the Patterns, the impacts identified are roughly the same, whatever the land use database used. The impact of the attractiveness map is not as obvious, but can be seen quite clearly in our analysis of the area's urban framework.

We also observed that our results differed with the land use database used.

5.3 Analysis of the results obtained from LUCSIM

As mentioned above, for want of time, we were unable to develop any real strategy for analysing the results obtained from LUSCIM. Though the theory behind its operation is very simple, LUCSIM finally proved to be quite complicated to use in practice and the models obtained merit a far more in-depth study than we were able to undertake.

5.3.1 Operation

Detailed feedback follows concerning the various steps conducted during our testing:

- Regarding the decision tree:
  - Processing times can be long. The degree of precision of the source data has such a marked impact that we were unable to run modelling processes with our most detailed data.
  - It is difficult to verify the impact of a Suitability map (attractiveness map or potential model): while there are sometimes conditions that specifically use the Suitability map or a change in the number of rules, many rules are strictly identical with or without the Suitability map.
- Regarding the modelling process:
  - It is possible to incorporate a constraint such as Potential/Suitability map, which has a real impact on models. However, we were unable to analyse its impact in any detail.
  - It is possible to incorporate a Markov chain constraint (which constrains the amount of change). However, this does not imply that the software will be capable, given the transition rules assigned to it, to change the area sufficiently to attain the maximum set by the Markov chain.
  - Processing times can be long: processing time depends not only on the size of the study area but also on the number and complexity of the transition rules.

5.3.2 The modelling processes

Over and above the software's operation, we ran a large number of modelling processes. Though, for want of time, no detailed analysis was performed of each one, the following results were observed:

- At each step or iteration of the modelling process, the transition rules are based on geographical conditions that may or may not be met for the study area:
  - A rule that cannot be applied will have no impact at all in the modelling process,
  - A rule that can only be applied on a very small portion of the area will have a very limited and very localised impact in the modelling process,
  - A rule that, on the contrary, can be applied to large sectors of the area (unless it is a Markov chain constraint) will have a marked impact in the modelling process, even if its impact will, in principle, remain localised.
- It would appear that the majority of rules with some degree of complexity have geographical conditions that stop them having anything more than a very limited and localised impact at each iteration. They generally end up not being able to be applied at all.
- Moreover, we have only ever modelled changes in a single type of area: discontinuous urban fabric). All other types of land use can only diminish. For certain types of land use that are clearly predominant in our study areas (i.e. forests and agricultural land), this has only a minor impact on the applicability of the rules, in principle. For others (in particular all of the other developed areas), it will rapidly make many of the rules' conditions inapplicable. We tried to limit this effect by removing all rules that resulted in the conversion of these other developed areas. Despite this, because the Discontinuous urban fabric had expanded, these areas had become more distant and many of the conditions (and hence the rules) were no longer applicable.
- It is not always possible to attain the threshold levels laid down with the Markov chain.

Visual analysis of the models produced by LUCSIM in fully-automatic mode reveals certain phenomena:

- Examination of the models produced shows that some sectors never change.

- Some areas, on the contrary, change, and sometimes the changes observed resemble rather conventional urban densification, more or less linear development or spontaneous urban development.

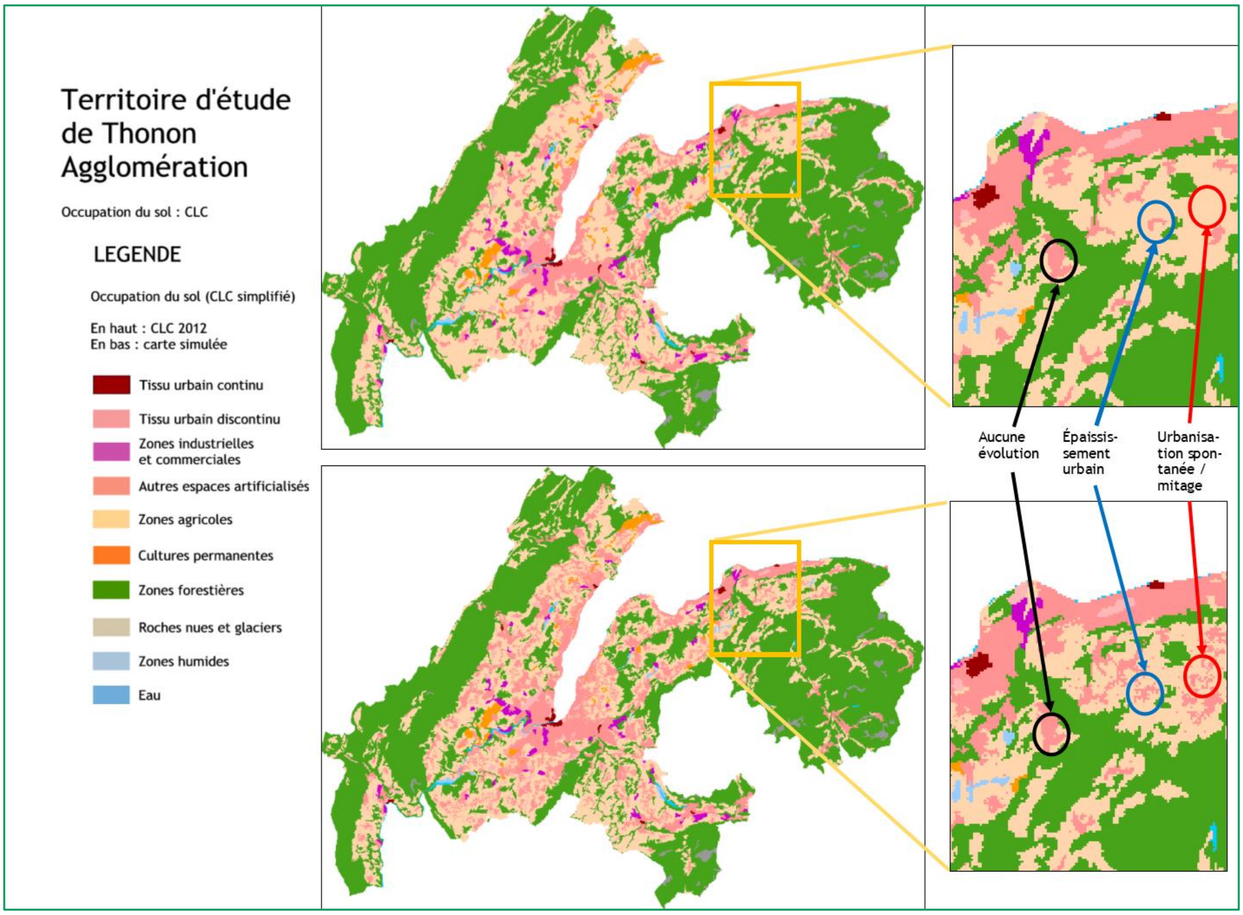

Figure 25: Illustration in the Thonon Conurbation study area of phenomena modelled by LUCSIM (no change, urban densification and spontaneous urban development)

- Then there is another type of phenomenon that is impossible to link to a real-life phenomenon. This phenomenon is the result of the reiterated effect of a combination of rules that, at each step of modelling, create the sufficient conditions for them to be applied again. This tends to appear with time as the number of iterations in the simulation increases. The result is the appearance of development pockets in the shape of "snakes" or "oil stains".

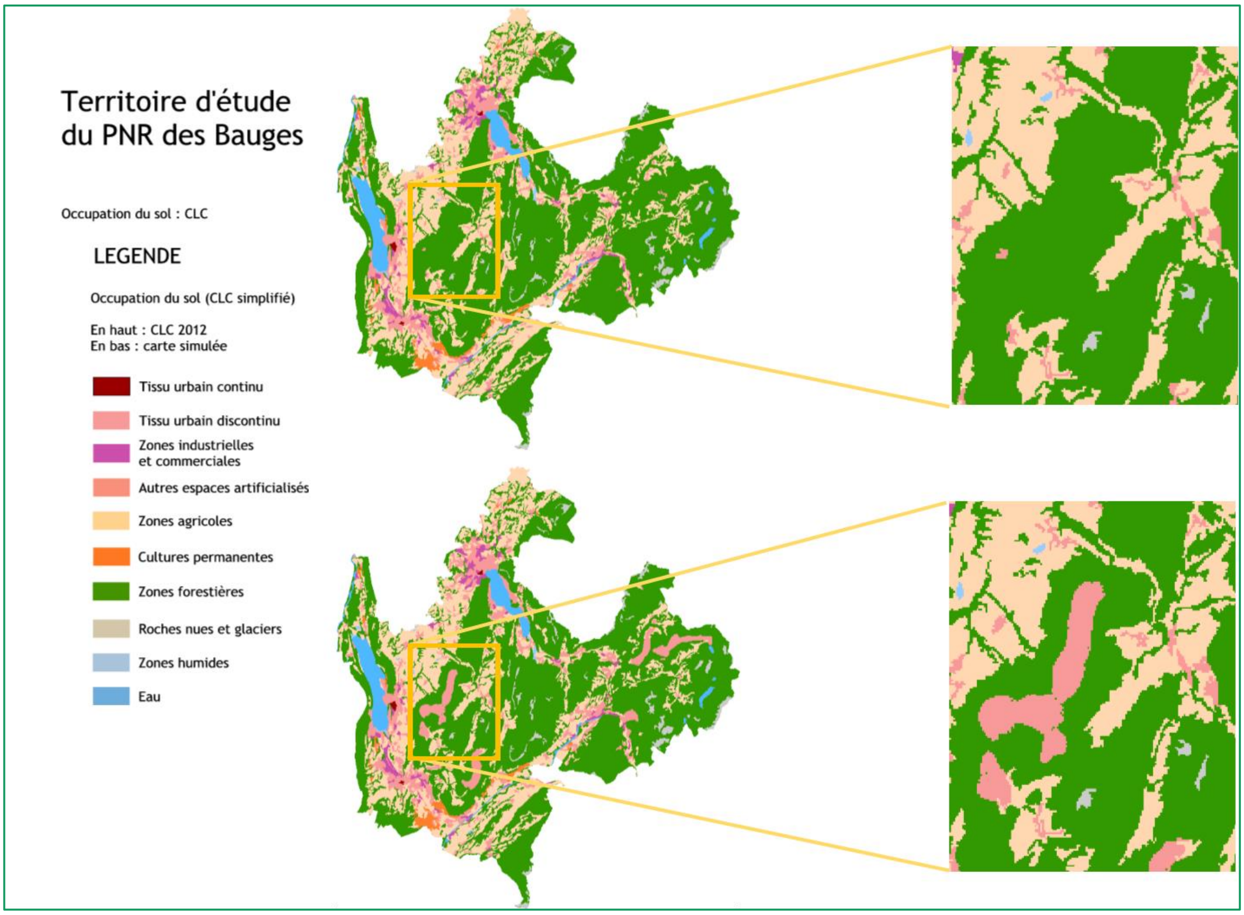

Figure 26: Illustration in the Bauges Regional Nature Park study area of the "snake" phenomenon modelled by LUCSIM

The models obtained in our two study areas are quite dissimilar in this respect.

Though our two study areas are similar in size (≈ 2,600 km²), the developed areas are markedly more extensive in the Thonon Conurbation (36,694 ha) than in the Bauges Regional Nature Park study area (23,037 ha), and the urban sprawl is also more marked there between 2000 and 2012. It is very clear that our two study areas were not processed in exactly the same way by LUCSIM:

The changes observed between 2000 and 2012 have a direct impact on the definition of the change rules by decision tree within LUCSIM. They are much easier to determine and there are more of them in the Thonon Conurbation study area than in the Bauges Regional Nature Park study area. For all of our tests, the decision tree yielded between 18 and 30 transition rules for the Bauges Regional Nature Park study area and between 89 and 169 rules for the Thonon Conurbation study area (with a strictly identical modelling strategy);

In the modelling processes, the "developed" quantities increased by between 1,500 ha and 8,400 ha (the maximum threshold used with the Markov chain) in the Bauges Regional Nature Park study area, and by between 7,800 ha and 14,800 ha (the maximum threshold used with the Markov chain) in the Thonon Conurbation study area.

With regard to the number of iterations before modelling stopped, certain modelling processes required up to around 100 steps in the Bauges Regional Nature Park study area, but never exceeded 30 stages in the Thonon Conurbation study area. There is no obvious connection between the quantities developed and the number of iterations. On the other hand, the higher the number of iterations, the more likely we are to see "impossible" phenomena such as "snakes" (cf. illustration above).

The thresholds set by a Markov chain, which differ for baseline and strategic models, were attained for 4 out of 9 models in the Bauges Regional Nature Park study area, and for 7 out of 14 models in the Thonon Conurbation study area.

We were able to run a final series of modelling processes for the Thonon Conurbation study area using the HRL Imperviousness data. We artificially decreased the precision of the information in order to have a pixel size of one hectare (the same as for CLC). For these modelling processes, we applied the decision tree for each type of land use in an endeavour to have rules that, theoretically, allowed us to change all of the types of land use concomitantly.

Since the results were obtained at the very end of the assignment, we were unable to analyse the results yielded by this data.

6 Results and feedback for the modelling programs

6.1 Modelling with FORESIGHT

The FORESIGHT software, in itself, is easy to learn to use and has a detailed user guide that rapidly equips users to begin modelling the area's development.

The modelling principle is clear and quite easy to grasp because the phenomena described can be directly linked to actual observations on the ground (urban scattering and linear development, for example, or the land take, etc.).

To recap, we had a number of objectives for our testing programme:

- Model development in the area using separate databases;
- Model different scenarios, differentiating the scenarios on the basis of the attractiveness map, land take and the urban sprawl patterns.

We had no difficulty incorporating our two databases, which differed in the precision of the information. However, it should be noted that the modelling processes used a minimum mapping unit of one hectare, which led to a "simplification" of the most precise data. In the cross-border Thonon Conurbation study area, we did not have a uniform layer for the entire land use area that was more precise than CLC.

Moreover, it was not possible for us to test the incorporation of our own attractiveness maps[41]. We nevertheless managed to produce a workaround solution using the software's module for creating the attractiveness map. We were able to define land take and urban sprawl patterns, which are modelling input parameters, for each of our scenarios.

The visual analysis of the results, in particular, highlights the impact of land take and the patterns of urban sprawl. It was also possible to identify the impact of the distinctions added to our attractiveness maps, even if, on the other hand, it was more complicated to measure the latter in practice.

In the Bauges Regional Nature Park study area, for which we were able to test two data sources (CLC and OSCOM) for defining the initial urban map, the results are not identical. The data source used has an impact on the results. In spite of recalibrating the OSCOM information to a one-hectare minimum mapping unit, its level of precision affected the modelling process. Whatever scenario we use, with OSCOM, urban development is more dispersed over the whole area, and the quantities of pixels created vary with the minimum mapping units studied.

In the light of the testing carried out in the ASTUS project, we can state that the FORESIGHT software can be a useful tool for modelling urban sprawl in an area. This easy-to-use software nevertheless has useful features (urban sprawl patterns, link between transport infrastructures and urban development, attractiveness map) that make it possible to adapt the concrete specifics of the modelling processes to the areas. Apart from the software's numerical parameters, which have to be calibrated beforehand, the attractiveness map theoretically offers real possibilities for factoring in, for example, some or all of the area's geographical information. This makes it quite simple for users to link it to the area's urban planning and development documents. Even so, a major drawback is that we were unable to incorporate our own attractiveness maps into the software during our testing programme.

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[41] After further testing, we were able to incorporate one of our attractiveness maps into FORESIGHT. There is no way to do this through the *Pre-processing* tab. However, it was possible to generate the *.gif file for one of our attractiveness maps directly through ArcGIS. Users will need to ensure that the resolution and extent are strictly identical to those in the files generated by FORESIGHT in the *Input* folder for the *Initial Urban Map* data, for example. The file was then copied into a model's *Input* folder, where it was recognised by the software *(Preview* in the *Initial settings* tab*)*, then used to generate a model based on our own attractiveness map.

In any case, given that the tool was capable of producing an image of what our study area might look like in the future, it delivers information that may be of direct interest to an area's decision makers, insofar as it shows the impact that urban sprawl might have on urban sprawl in the area, the impact of certain policy directions taken in urban planning documents and the combined, large-scale effects of all of these urban planning documents

With certain precautions, such as generating multiple models and combining the results, it is also possible to carry out a fine-scale analysis of the maps. This approach would provide a means of studying the impact of new urban development on aspects such as networks, mobility, infrastructure and facilities, and/or urban development patterns.

6.2 Modelling with LUCSIM

As far as the software's operation is concerned, LUCSIM is easy to start using in "fully automatic" mode, as we saw from our own experience in the ASTUS project, even if the user guide is at best succinct

To be able to use the decision tree to automatically define transition rules, and to use a Markov chain constraint to cap the quantity of land use change allowed during modelling, it is necessary to have two land use layers at two separate dates. Moreover, because the decision tree works on changes that occurred between these two dates, the more changes there are, the more the results will be precise and useful.

Using the decision tree makes it possible to quite quickly obtain the first rules for changes in the area, in order to be able to execute our first models. Note that the precision of the initial information has a major impact on the processing time necessary for the decision tree to yield its results, ranging from a matter of minutes when using CLC data to several days for the more detailed databases we studied, such as HRL or Theïa (with no guarantee of a result). Note also that the number of rules generated by the decision tree will have an impact on the subsequent model.

The rules generated by LUCSIM are exclusively geographical. The development of a given cell will depend on whether, in a specified neighbourhood, there are certain quantities of the various types of land within an initial land use layer. The effects of this type of rule are difficult to represent or to relate to traditional phenomena such as linear development or urban scattering, for example. LUCSIM's "fully automatic" operating mode is not fully explicit about this aspect.

To recap, we had a number of objectives for our testing programme:

- Model development in the area using separate databases;
- Model different scenarios, making each one different by using an attractiveness map (and the potential model included in LUCSIM) and a constraint such as a Markov chain.

We had very few problems modelling with CLC in the *Discontinuous urban fabric* mode. However, because of the processing times per decision tree, no results were obtained with the HRL and Theïa databases. For the HRL database, after simplifying the data by changing the minimum mapping unit from 20 metres square to 100 metres square, we were able to model the Thonon Conurbation study area.

No in-depth analysis of the results we obtained with LUCSIM was able to be undertaken.

After simply studying the transition rules obtained through the decision tree and through visual analysis of the models obtained, we are now in a position to make a number of remarks about LUCSIM's operation:

- While the Markov chain can be used to cap growth in certain types of land use, it is not always possible to attain these thresholds and often the modelling process stops before this because the transition rules can no longer be applied in the area.
- The attractiveness map, *Suitability map* or potential model used by LUCSIM have an impact on the definition of rules by the decision tree and on the models themselves.
- The changes do not include any notion of time, so are not regular in time or space. The first iterations of the model generally generate extensive change, while the last ones generate only very minor change.
- The distribution of the changes generated by the models for the area is far from uniform:
    - Some sectors display no change at all, while other show significant change;
    - Changes to the *Discontinuous urban fabric* sometimes resemble traditional urbanisation phenomena, such as urban densification, linear development or urban scattering;
    - Sometimes fictional phenomena known as "oil stains" or "snakes" appear.

Given these results, it would appear to be a very complex undertaking to draw a conclusion about this software's suitability for use as a decision aid.

In some respects, LUCSIM delivers very real benefits:

- LUCSIM's main advantage is that it can change different types of land use concomitantly, so is capable of modelling certain densification phenomena.
- LUCSIM can also identify and model the impact of certain interactions between the urban environment and the natural environment, and, if the initial land use layer is sufficiently detailed, between the different types of land use in an urban environment.

However, during the ASTUS project we were not in a position to test these possibilities in practice.