Time-Geographical approaches to Emergence and Sustainable Societies (TiGrESS)

(Cultural Ecodynamics at different Spatial and Temporal scales)

TiGrESS

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Workpackage 5

Running experiments with the Madrid Simulation Model

FINAL REPORT

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Introduction

The stakeholder engagement exercise described elsewhere (Hernandez, *ibid.* p 10 and 11) generated four critical problems in the *problem tree* of the Logical Framework Approach (LFA). These were:

1. Institutions and committees
2. Participation
3. Scientific information and accessibility
4. Land planning and Management Tools

The stakeholder engagement process has already addressed the first two of these four problems. That process not only generated seven policy options and negotiated substantial 'buy-in' from key stakeholders at five levels in the governance hierarchy (municipal, intermediary, regional, national and supra-national) but also achieved a breakthrough in the form of proposals currently under consideration to establish a sustainable planning observatory in the region. These initiatives not only involved members of the TiGrESS team, but also included researchers from the Polytechnic University of Madrid, who we expect will take a prominent role in future developments. All the stakeholders (the Spanish Observatory for Sustainability, the Ministry of Environment, the Regional Directorates with responsibility for Agriculture & Rural Development and Environment & Land Planning, and two of the case study Municipalities) are also engaged in this development.

We are especially pleased that the final stage of the stakeholder engagement, which we had reasons to believe could easily become confrontational, has instead produced a genuine synergy which we hope will soon encourage developers to join with us. This was not originally planned as a TiGrESS deliverable, but we decided to support it in any way we could. Evidently, the most effective way of doing this would be to put extra effort into resolving problems 3 and 4 - the need for strategic scientific information and effective land planning tools. That is the subject of this final section of our report.

Stakeholders need to understand the likely impact of the seven interventions we have developed as realistic policy options aimed at sustainable development and facilitating convergence in the region. TiGrESS was well placed to assist with this work. We had substantial data, including GIS data about the region and about the effects of fragmentation. We knew a lot about legislation and the planning process and we had developed a coherent model of land-use, including a strategic understanding of land-use conflict in three zones across the region. All this research seemed to suggest the outline specification for an integrated decision-support system that could be used to explore the policy options as a series of simulated 'what if?' scenarios that could be explored using a Time Geographical simulation.

In this respect, we were fortunate that RIKS had considerable experience of building such models using a cellular automaton system to represent the pixels on the map. Various members of the TiGrESS consortium had been active in an earlier project (Modulus) that developed an integrated Decision Support System for Marina Baixa and the Argolid Plain (Oxley *et al*, 2004; McIntosh *et al,* 2005). After some discussion, it was agreed that Carlos Hernandez Medina, Inge Uljee and Maarten van der Meulen would co-ordinate model development. The model was implemented in the METRONAMICA programming environment developed at RIKS at the end of the project. METRONAMICA can be used to construct dynamic land use models that can be integrated with Geographical Information Systems (GIS) data layers.

The Madrid model (Hahn *et al* 2006) was completed just before the project ended and has been used at Newcastle and Madrid to simulate all seven policy interventions across five distinct scenarios. This report is to describe the modelling environment and interface; to introduce the scenarios and illustrate them by presenting simulation output in the form of data and dynamic maps.

How the Simulation Environment Works and Why we Simulate

METRONAMICA is a decision support system build with the GEONAMICA® application framework. The METRONAMICA simulation environment calculates the transition probability for each cell and function at each simulation step. In the normal course of things, each cell will change to the land use function for which it has the highest potential, but less probable transformations are possible. The transition probabilities determine the likely future pressures on the land. By providing a series of dynamic maps and summary data, the system can be used as a planning tool for those responsible to the design of sound spatial planning policies.

The transition probabilities for each cell (a cell is a measurable piece of land) are determined by four factors that represent exogenously defined demands for land in each category. These factors are: *suitability* (for a given use), *zoning* (by planners), *accessibility* (particularly road networks) and *internal dynamics.* These do not represent all the factors, which influence land use changes, but are the ones we have chosen for simulation. Other factors, such as land regulations, demographical trends, and the local and regional decision systems are handled as policy drivers – recognisable scenarios that can be incorporated into the system. There are actually five scenarios explored in this report. The policy drivers are often understood as constraints on the system which frustrate certain types of land use by modifying transition probabilities locally. These include as population growth, municipal land planning guidelines and the new organic farming market.

The scenarios are based on the territorial analysis and fieldwork described in Hernandez, V. 2006 *ibid.* These scenarios are established in response to stakeholder suggestions and needs. We naturally restricted these to interventions that appear socially and politically realistic – i.e. represent the action of recognisable policy instruments. In designing them, we took account of past and the current implementation of policies and also of expected developments. However, we also took account of inertia in the decision system caused by the huge diversity of stakeholder communities and the complexity of the planning system. There is a wide range of possible futures, each of which is consistent with our understanding. These cannot be explored without the assistance of a computerised model and the use of policy scenarios.

Finally, we learned a lot about possible interventions which, although not likely in the current political climate appeared possible and desirable, at least from the perspective of some stakeholders. These ideas, which came up in the course of interviews, formed the basis of some scenarios. The aim of the modelling exercise is to provide a new source of information to town planners and decision makers at the different levels of governance. Many of these interventions were already known to them through the booklet *"Hacia una planificación sostenible en la Comunidad Autónoma de Madrid: Directrices y Recomendaciones"* (Encinas et al, 2005), but no impact assessment had been undertaken. These model runs were to facilitate that assessment. The simulations will provide information about the expected consequences of the seven policy interventions. Consequently, this experience would lead to take responsible actions about the development of Madrid region.

Micro-Modelling land-use change

METRONAMICA can be used to explore and visualize land use change effects of different scenarios tried out for the three key dynamics in the region of Madrid. Each dynamic is characterising a landscape pattern of the region: *Dynamic 1* is located in the East, the South-east and the Centre; *Dynamic 2* typifies the geographical area of the North and the North-west; and *Dynamic 3* is situated in the South, the South-west and the South-east. For further information on landscape dynamics see Encinas et al. 2006 *ibid.*

The model consists of dynamic spatial models operating at two geographical scales: micro and macro-scale. The macro-scale sub-model represents general trends of land use change over long periods and static factors (like geology or geomorphology). The micro-scale sub-model determined the transition potential of the land, cell by cell and it is the micro-scale we will describe first.

The Madrid region (CAM) covers a territory of approximately 8.000 square metres and six million of inhabitants (for further information, see Hernandez 2006 *ibid*.) This area is represented as a mosaic of equally sized grid cells. All together, they constitute the land use pattern of the Madrid region. Land use in the CAM is classified in nine categories: *Forest unit & riverbanks, Urban, Shrubland, Pastures, Abandonment, Crops, Irrigated crops, Crop Mosaics -vineyard & olive tree, and Water* (Encinas et al. 2006).

Each cell covers an area of four hectares and makes transitions annually. Micro-scale simulation considers environmental factors as well as interactions between neighbouring cells. The detailed allocation of activities and people within cells are modelled using cellular automata at the micro level. Each automaton represents a small territorial unit – a territorial cell. The area modelled was represented by a mosaic of 199.920 cells, each of four hectares.

CAM covers an area around 120 by 150 kilometres, divided in cells of 200 by 200 metres. Some of the nine land use categories are modelled dynamically, though a few remain static in the model. Depending of their dynamic behaviour are organised in the following three categories of land uses: "vacant", "function" and "feature" (Hahn et al. 2006 *ibid*)

- A "vacant" land use is a land use for which the amount of cells in such state depends on the value of its transition potential. This will only change to another "vacant" state if the transition potential for the other one is higher. i.e. *Abandonment*. The macro-model does not specify the cells required at each simulation time step. The amount of cells in the vacant states will remain unchanged unless the "function" land uses are taking more or less cells.
- A "function" land use will change the amount of cells required for that stage depending on which the macro-model determines. i.e. *Forest, Urban, Shrubland, Pastures, Crops, Irrigated crops* and *Crop Mosaics*.
- A "feature" land use is a non-dynamic land use. They will not differ due to the changes of other land uses or dynamics in the model. Although, the happening of a "feature" land use would influence the location of the "function" land uses. i.e. *Water*.

The model developers (Carlos Hernandez Medina, Inge Uljee and Maarten van der Meulen) specified the basic information used in the model and the algorithm. Four factors determine whether a piece of land (each cell) assumes a particular "function" or is kept "vacant".

At the most fundamental level we see change effected by sets of *cellular automata transition rules* that represent micro-level dynamics. These rules estimate the probability of change for each cell by examining its own and neighbouring land-uses. A set of rules determines the degree to which it is attracted to, or repelled by a given land use. The forces of 'attraction' or 'repulsion' between the different functions and features are established by a 'negotiation' between neighbouring cells. The rules are modified in a way that takes account of socio-economic and environmental factors and landscape suitability for a given use. This negotiation determines the interaction between the nine land uses categories. These rules (the inertia, the attraction and repulsion forces, and certain economies of scale) were determined during model calibration.

Macro-level dynamics

The territory as a whole consists of all the cells simulated by automata. As land-use within each cell changes, so too does the map formed by putting all these cells side by side. In this way, macro-scale dynamics are determined by the aggregate effects of the micro-scale rules, modified by the synergy between neighbouring cells. The output of this synergy can readily be represented using dynamic maps that contain all the cells.

If this were all METRONAMICA could do, we would have a perfect 'bottom-up' model in which all macro-scale factors were deducible from micro-dynamics. However, METRONAMICA also allows us to influence the system on a macro-scale using maps to represent scenarios and drivers. As with all the models explored by TiGrESS (Winder, 2006 *ibid*) the Madrid model represents multi-scalar Time Geography (MSTG). Macro-scale maps represent the top-down constraints; the cellular automata simulate bottom-up 'adaptive' behaviour. It is 'adaptive' (i.e. not deterministic) because the cellular automata use transition *probabilities* not hard and fast rules and consult neighbouring cells before calculating transition potentials. Emerging patterns and innovations can occur if, and only if, the constraints permit the cells to explore new types of synergy on the micro-scale.

The following are important static maps. They capture many of the distinctive constraints on the decision process at micro-level. They can be used to explore a range of policy scenarios and their possible effects on a landscape populated by cellular automata whose behaviour, though responsive to those constraints, retains a measure of adaptive potential.

Suitability maps. Suitability is represented in the model by one map per land use function. The term 'suitability' describes the ability of each cell to support a particular land use function. It is composite measure, prepared in a GIS on the basis of elevation, soil quality, slope, aspect, etc.

Zoning maps. Zoning or institutional suitability, is based on guidelines plans from the local, regional and national authorities which took into account ecological protected areas and buffer areas. Three periods of planning were established: 1989-1997, 1997-2002, 2002-2025 and they specify which cells can and cannot be taken in by the particular land use. Zoning is characterized by one map per land use function. There are four zoning states possible (discussed in the next section).

Accessibility maps. The accessibility of each cell is calculated in the model relative to the infrastructure networks (roads) and river systems. It accounts for the distance of the cell to the nearest link on each infrastructure elements or water resource. Transport system is very important for new urban developments and hydrographical system for irrigated crops.

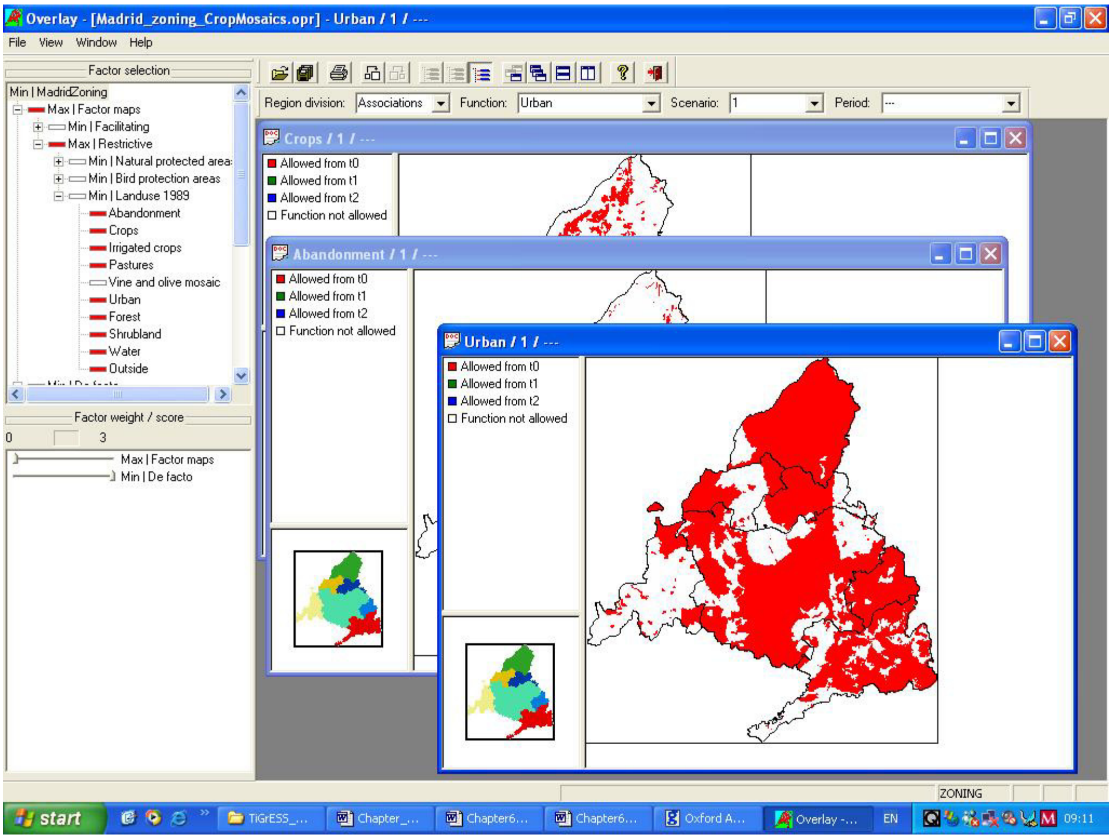
In general, *suitability maps* are static – the soil and geomorphology cannot change. However, both *accessibility* and *zoning maps* can be changed. It is possible to modify planning laws or to construct new roads, for example.

Creating the Scenarios

This section describes the tools METRONAMICA provides for creating scenarios. Input maps (land use maps 1989, 1997 and 2002, *suitability maps* and *zoning maps*) were the work of the Spanish team lead by Carlos Hernandez

Medina. The RIKS team calibrated the model by fine-tuning the dynamics of individual cells.

The OVERLAY Tool in METRONAMICA was used to prepare the *zoning maps* that represent macro-scale scenarios. These maps may be modified to produce certain types of macro-scale scenario. The tool enables users to select four zoning states possible for each cell of each land use function: the activity is present from the first period onwards (red box), if the activity is permitted from the second period (green box) or from the third period (blue box), and the activity is never allowed in the cell (white box). However, in this case only two zoning states were needed, as the following screen dump shows. The *zoning maps*, understood as macro-constraints, are used to represent natural protected areas and restriction of land uses.



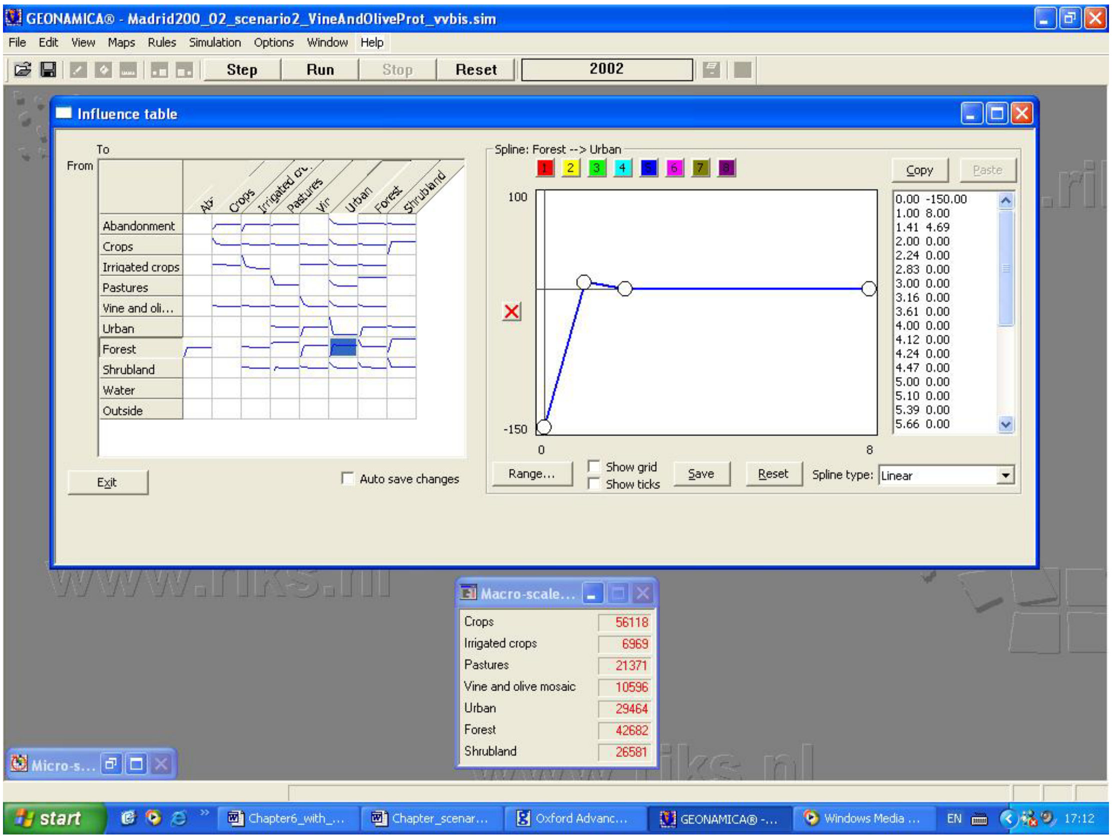
GEONAMICA® is open after these maps are created and both *zoning* and *suitability maps* are imported. GEONAMICA allows us to modify rules that operate at the level of the individual cell.

These rules are expressed in terms of distance functions that define the interaction between each pair of land uses among neighbouring cells. The micro-scale model is represented in the form of an "influence table" (See the window below) that displays the responses graphically.

The interaction of land use categories is defined using a series of projections connected by linear interpolation showed in the graphic on the right side.

The distance between cells runs along the horizontal axis and the vertical axis displays the influence between the pair of land uses.

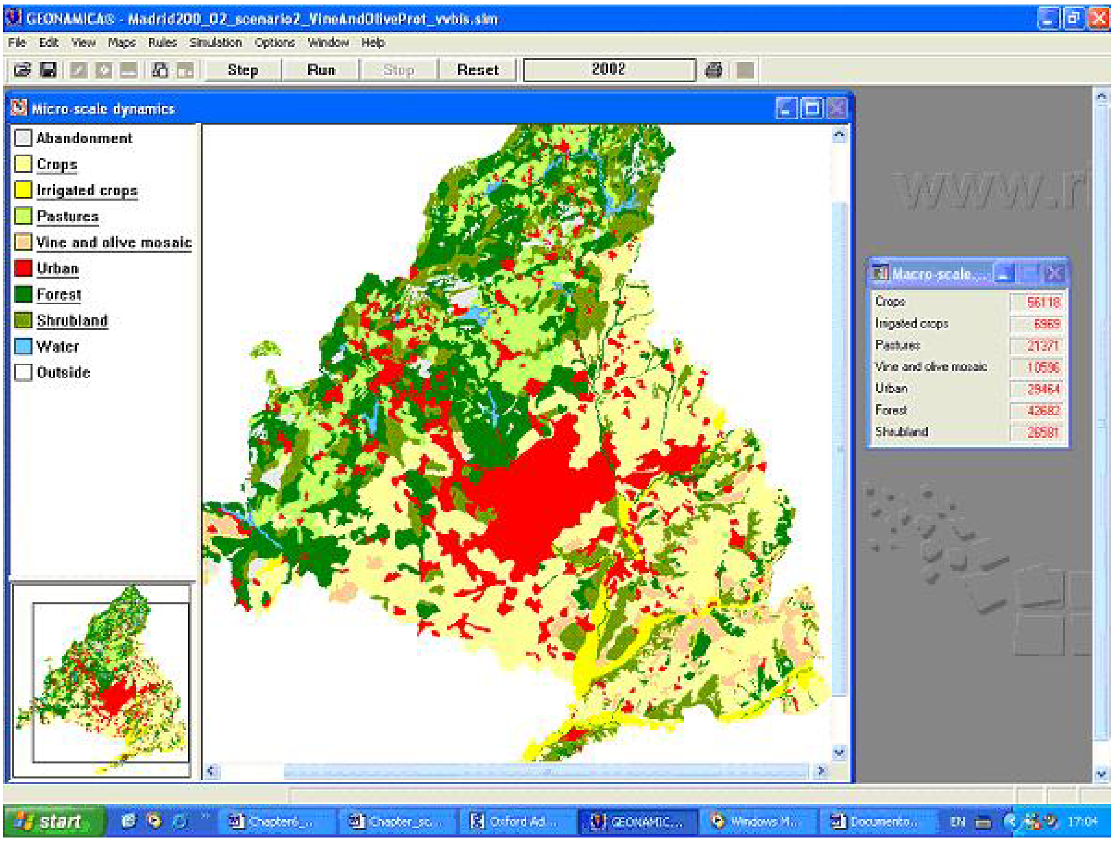
For example, the screen dump below shows that, when Forest will not easily change into Urban land. As the distance between cells is getting further, the effect changes and has a slightly positive effect. This represents the attractiveness of nearby natural sites to residents in urban areas. After the distance of two cells, the influence is null.



The micro-scale and macro-scale dynamics windows are opened as soon as METRONAMICA starts. The macro-scale effects of all these micro-scale processes are visible in the window below, as the land use will change at each simulation step and the window will be updated.

The map is updated dynamically to represent the aggregate effects of micro-scale dynamics and the resulting land uses are displayed in the map area which represents of the modelled region. However, the outputs of the macro-model are not directly visible, but are presented in a separate window as aggregate statistics.

The user can control the simulation using the following the buttons: *step* (execute one simulation step), *run* (execute the whole simulation) and *stop* (the simulation is paused).



After the simulations have run, we use the METRONAMICA Map Comparison Kit (MCK) to analyse and compare output and input maps of the model. MCK allows us to compare the results for each category of land use in a very flexible and intuitive way.

The Scenarios

Each of the scenarios described below runs from the land use map set in 2002 to 2025 - it therefore simulates both the past and the immediate future.

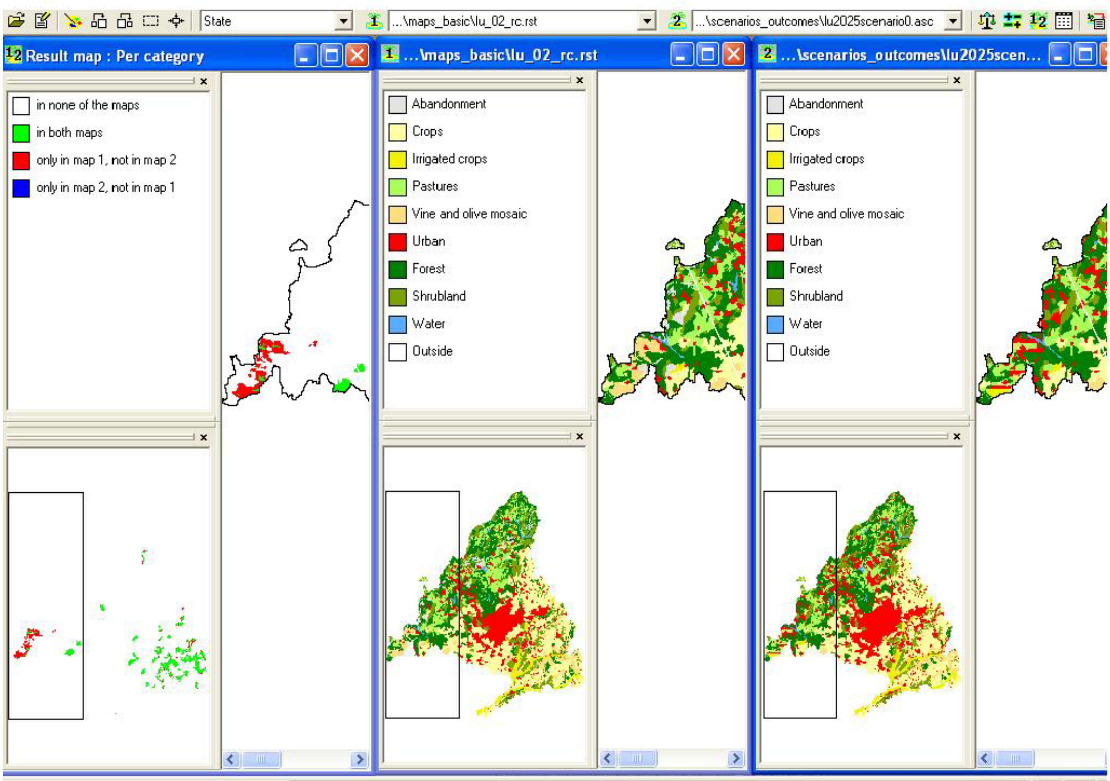
The observation and analysis of the predicted situation in the territory will be helpful, as a basis for negotiation between stakeholders, in what is undoubtedly a sensitive political situation. Local residents, building constructors, ecologist groups and regional government all have different and sometimes antagonised perspectives.

The stakeholder engagement process described elsewhere generated a high degree of interest and buy-in among stakeholders. The following scenarios represent a set of the most requested situations and interventions. The topics we will address include: urban growth, loss of agro-ecosystems and no co-ordination between parallel institutions.

Scenario 0: Business as Usual

This is the baseline scenario established by Carlos Hernandez Medina and RIKS in Madrid and Maastricht. It was validated to simulate land use change between the two periods of planning (1989-1997 and 1997-2002) and then extrapolated to 2025. The RIKS team made manual corrections during the calibration of the model to ensure goodness of fit. See Map 1.

Map 1



The validated model simulated observed data well and predicted the following main changes between the nine land-use categories are:

- Much abandoned land would be transformed, mainly into urban use. Some patches of new urban use are also converted from pastures and shrubland, but in a smaller proportion. This urban expansion is mainly predicted to the mountainous area in the northern region, where the housing demand is currently increasing.
- Areas under crops that are surrounded by urban areas, or by forest and shrubland borders are often converted to urban use.
- Cultivation of irrigated crops tends to spread towards nearby uses such as forest, shrubland and crops.
- Most of the crop mosaic patches in the South-Western are destroyed as urban use, pasture and irrigated crops takes over.

Scenario 1: Accelerated Urban Development

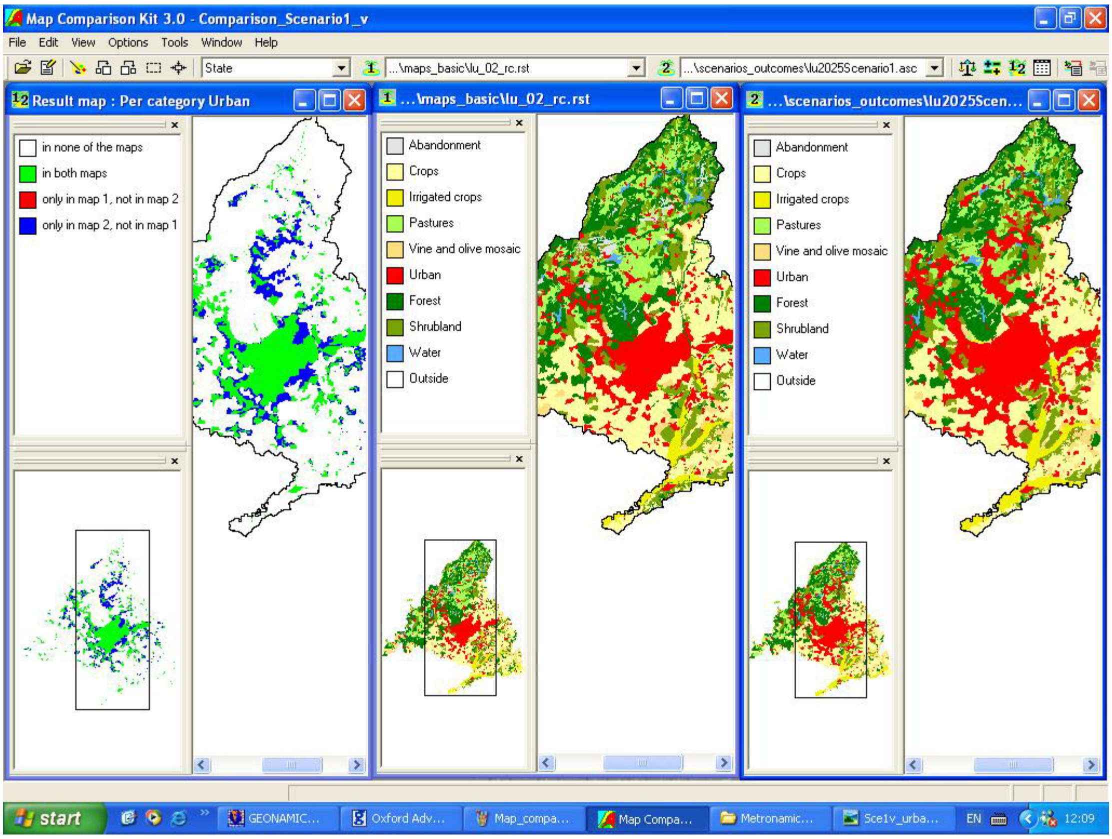
This scenario will simulate the perceived increase in demand for urban and residential development, based on the following analysis:

Forecast of continued population growth in the region in the next few years suggest an increase the demand for housing. According to the current plans of the Regional Government - the amendment of the Land Law 9/2001, urban land cover could increase by nearly 18% over the next years. This new regulation is due for immediate implementation according to the current governmental plans, which facilitate the reclassification of the 'rustic land - non protected' and the 'potential urban land - non compromise' categories (17.49% of the land is classified into both categories) into the 'potential urban land' category. The plans will in shorten the planning and consultation process and so accelerate development.

Thus, this scenario would block the development of reserves and protected land in the region and strategic land use management. This scenario represents a short-term change concerning to the urban land use perspective. We have simulated it over a period of four years (the life expectancy of a political unit). At the end of this four year period, this temporary acceleration is arrested.

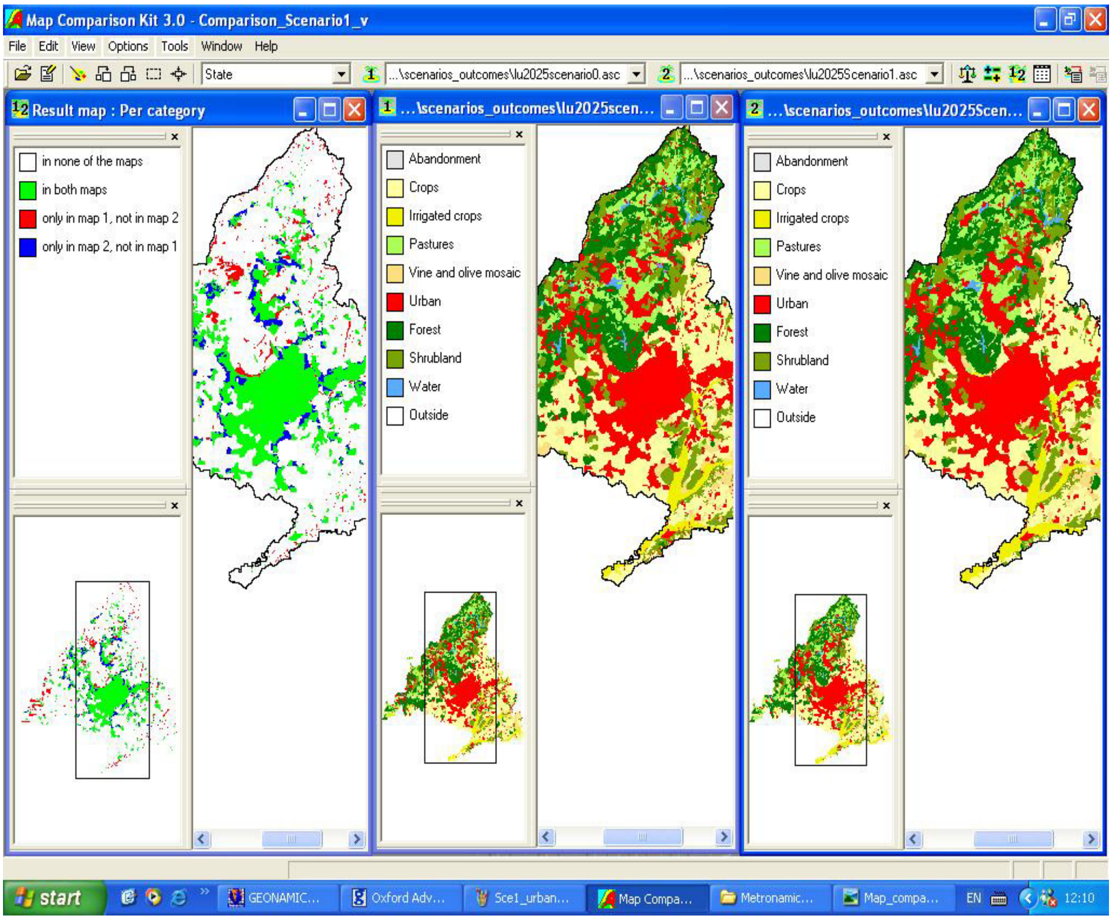
Urban use covers all the neighbouring areas of the urban centre and spreads over the Northern region in parallel with the infrastructures network. All the land uses in the urban edges are also transformed (See Map 2). The urban encroaching upon the urban centre is faster during the first 4 years (the political time-horizon) taking into account from 2006 (as it represents the year which the new proposals have been suggested). After accelerating urban growth until 2010 (the rules are modified in the micro model), urban growth decelerates so that the final urban area is the same as in the baseline scenario.

Map 2



The following map (See Map 3) shows the comparison between Scenario 1 and the Scenario 0 (baseline scenario) for urban land use. The patch of urban land grows differently between both scenarios. In the Scenario 1 (a faster initial urban growth) the urban land is occupying all the surrounded areas to the current urban ones, except in which is not allowed because of natural protection. Whilst, in the Scenario 0 the urban patches connected the urban centre to the Northern area occupying much abandoned land and forming isolated spots of urbanization all over the region.

Map 3



Scenario 2: Protecting Key Ago-Ecosystems

A selected group of stakeholders (chosen to include farmers, experts in the universities and planners in the Agricultural and Rural Development Department within the Regional Directorate) was shown the booklet described earlier.

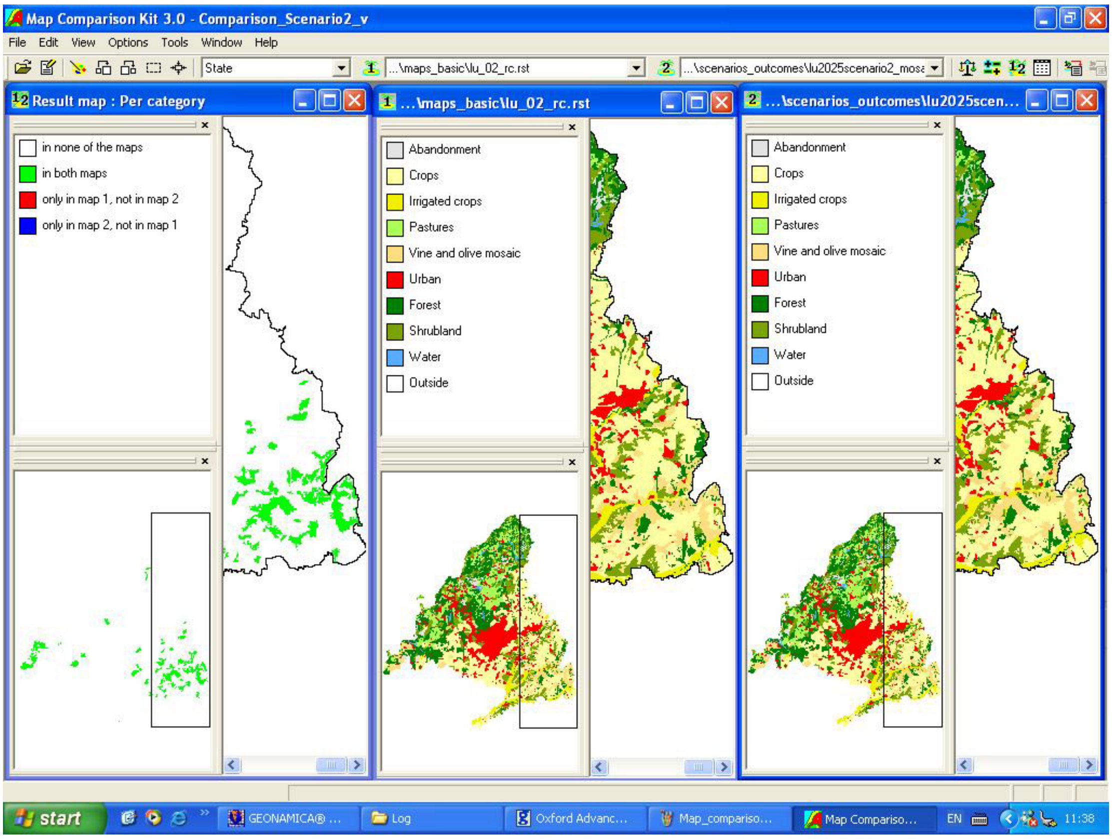
This group identified traditional farmlands and the strategic farming ecosystems as important sites for protection. The combination of olive tress, cereal crops and vineyards can be found in the southern region (including the southeast and the southwest). This mixture is part of the South-Madrid landscape and is well-known as Crop Mosaics. The maintenance of these agro-ecosystems would sustain traditional landscapes and a characteristic structure of land ownership, where the average plot is 0.5 hectares (INE, 2003) and land consolidation programmes have not been established yet. If we are to act, it is necessary to act now before holdings are consolidated.

The management of these protected spaces would create belts of sustainable agriculture. These belts would also encourage sustainable practices and improve the educational and tourist activities, as well as would act as limits to urban expansion. The farming areas would eventually be appreciated by their multifunctional use in the landscape, as the European rural development programmes are requiring in their future implementation (2007-2013).

We used the OVERLAY Tool to create areas where intensive farming and urban development would be discouraged. This scenario, then, is similar to the baseline scenario in every respect except that a macro-scale constraint is imposed that encourages traditional agriculture and conserves these sensitive areas.

In the map below, the combination of vineyards and olive trees, both typical Mediterranean crops, is the only land use category which keeps a fixed number of cells all along the simulation.

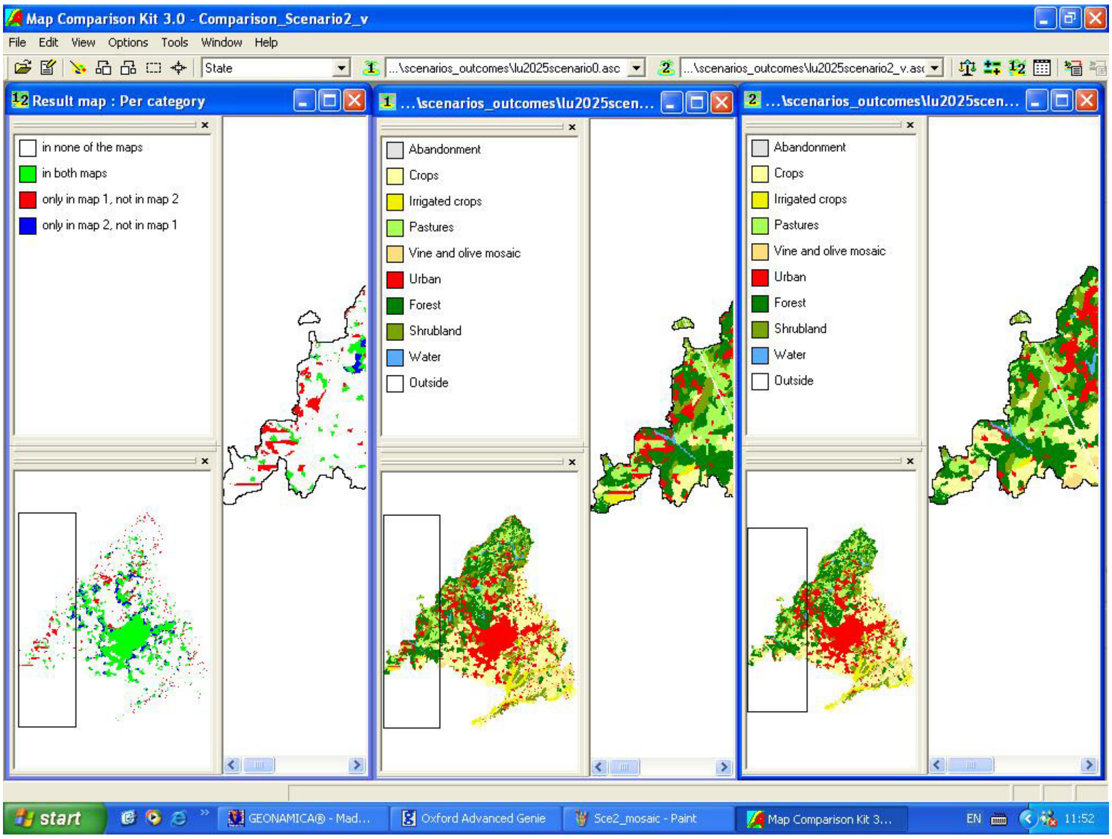
Map 4



The situation in the South-western is particularly interesting. Some of these spots belong to the Special Protection Area for Birds (SPA) called *"Encinares de el Rio Cofio y Alberche"* (Oak woods in the rivers: *Cofio* and *Alberche*). The rest of them are facing a competition for the use of the land, tending to disappear under the influence of subsidized farming and the infrastructure development.

The following screen dump (Map 5) shows the comparison between the baseline scenario and the Scenario 2 in terms of urban land use category. It is easily visible how this kind of protection would halt the urban expansion and other uses related to it such as irrigated crops, as this area is specially threatened because of the extension of the road networks. To view an animated screen dump of the south-eastern region, click here.

Map 5



Scenario 3: Creating Buffer Zones and Belts around Protected Areas

This scenario simulates a proposal made by environmentalists to establish 'ecological and zones of special use' to surround the Natural Protected Areas. These areas would include sites under the European regulations such as Habitat Directive (92/43/EC) and Birds Directive (79/409/EC) and sites under the National and Regional legislations.

A restraint on specific land uses covering a distance of two kilometres will be established to prevent the influence of external pressures. New land use basic maps were needed to create (GIS) which drawn the buffer zones. These were imported to the OVERLAY Tool, from which new zoning maps (land uses such as irrigated crops, abandonment and urban were limited within these buffers) were used for the simulation in METRONAMICA.

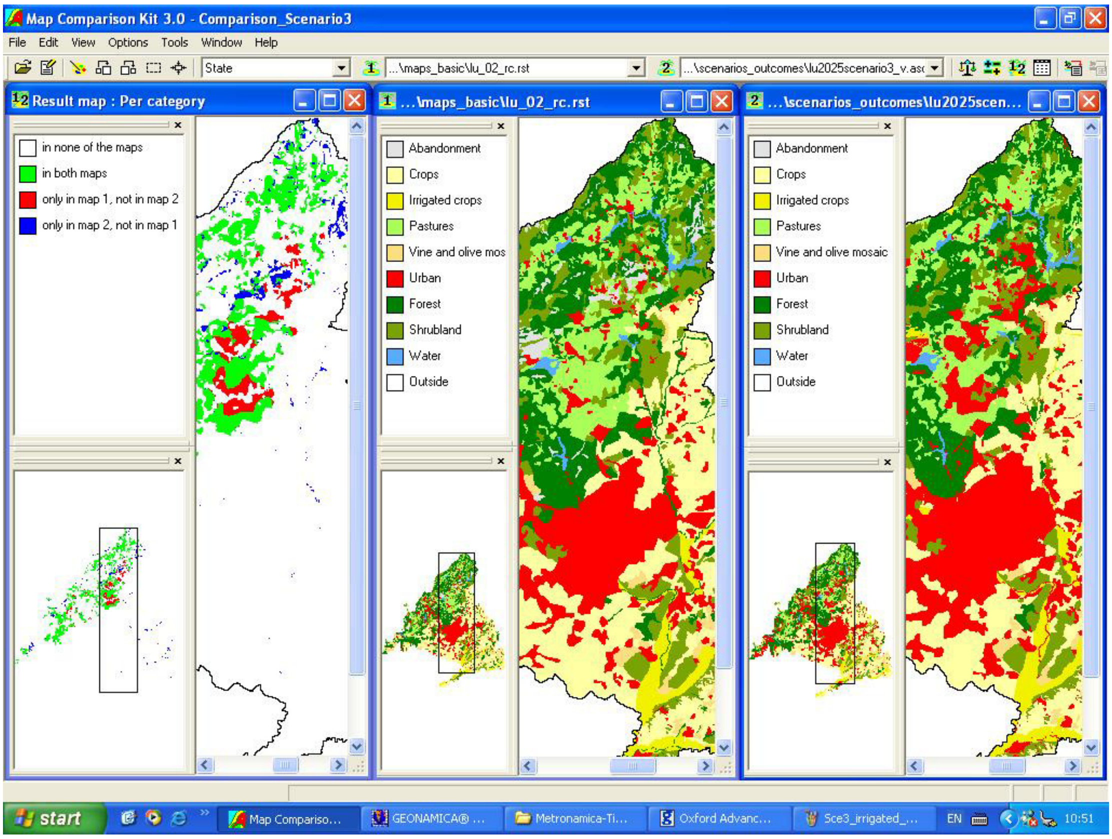
Belts of sustainable agriculture would be created to mitigate the impact of intensive land use on the most fragile territory, as well as, this measure would favour the creation of ecological corridors between the protected areas.

So far, new policy trends are supporting the maintenance of farming and livestock sustainable practices, but always within a network of protected areas, such as Sites of Communitarian Interest- SCI (LIC in Spanish), National Protected Spaces (EEPP in Spanish) and Sites of Special Protection Areas for birds- SPA (ZEPA in Spanish). In the case of the new European Agricultural Fund for Rural Development –EAFRD (Ministry of Environment, 2004) will be implemented within the sites under the Natura 2000 network.

Thus, the edges of the natural protected sites would be endangered if the current trends of the regional land policies do not evolve into the supra-national and national agreements. In other words, those key areas without any sort of protection for ecological conservation would run the risk of vanishing forever.

The following map shows the potentiality that specific categories of land use (such as pastures unit, which is strongly related to the forest unit as it represents a common land use all over the mountainous area of the CAM) have to cover these buffer zones.

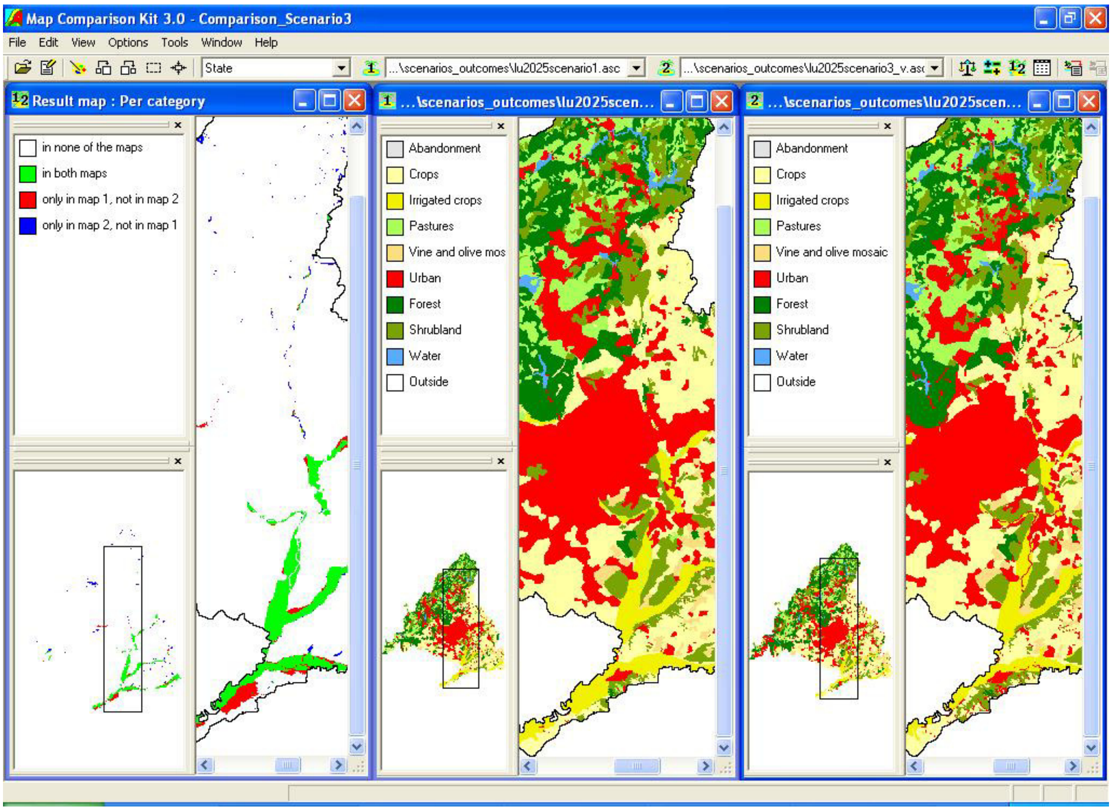
Map 6



Another result of the MCK is the Map 7 that compares the Scenario 1 and the scenario described here. The irrigated crops form a controversial category of land use, as both traditional and intensive irrigated crops are treated as part of the same category. High water demand crops oblige to install intensive systems of irrigation nearby main riverbeds, which occupy wide areas. However, traditional riverside plots, well known as *'huertas'* because of the horticultural crops, are better distributed all along the riverside and represent part of the typical riverbank ecosystems.

The screen dump shows land use changes as the system moves from an intensive irrigation system to well riverbanks conservation all along the line of the rivers. The restriction of this land use within the buffer zones could be argued in case of not having enough confidence to monitor the kind of irrigation crops are settled in the riversides.

Map 7



Scenario 4: Riverbanks and Wildlife Corridors

The MCK results above are relevant to the scenario explored here. Riversides and riverbanks have experienced the most drastically modified landscape on the whole of the region.

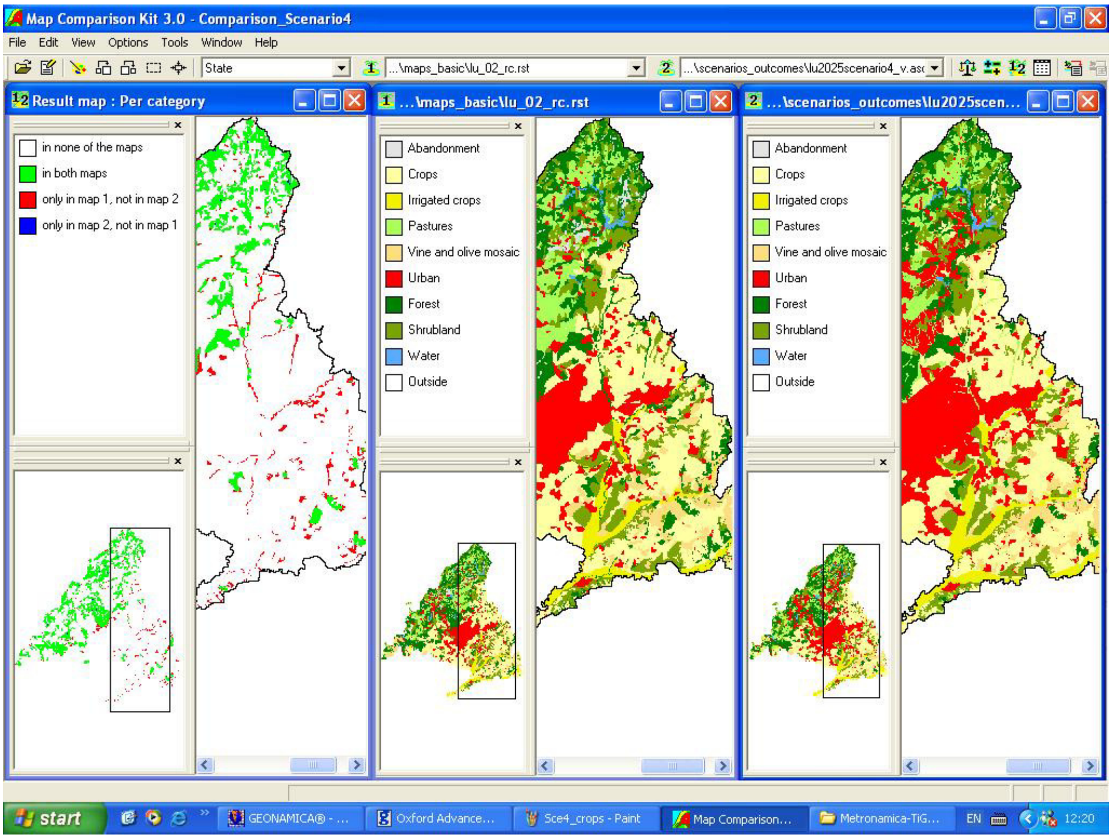
The national Water Law (29/1985) claims two restricted sections in each side of the main rivers: the first one 'track land' is 5 metres in width and the second one 'vigilance area' is 100 metres in width, where the uses and activities are controlled. Nevertheless, a higher restriction would help to avoid their degradation after what is being publicly by ecologist groups (Friends of the Earth, 1998).

New land use input maps were created in GIS, as for previous scenarios. A first strip of 200 metres in width from the river and a second strip extending that distance to 400 metres in width were drawn. Then the OVERLAY Tool was used to restrict land uses within both strips.

All the categories of land uses are constrained in the first 200-metre buffer zone except forest. In the second 200 metres, irrigated crops, abandonment and urban categories are restricted. This two-tier buffer zone was established in parallel strips along the length of rivers and streams to represent the effects of targeted recuperation work.

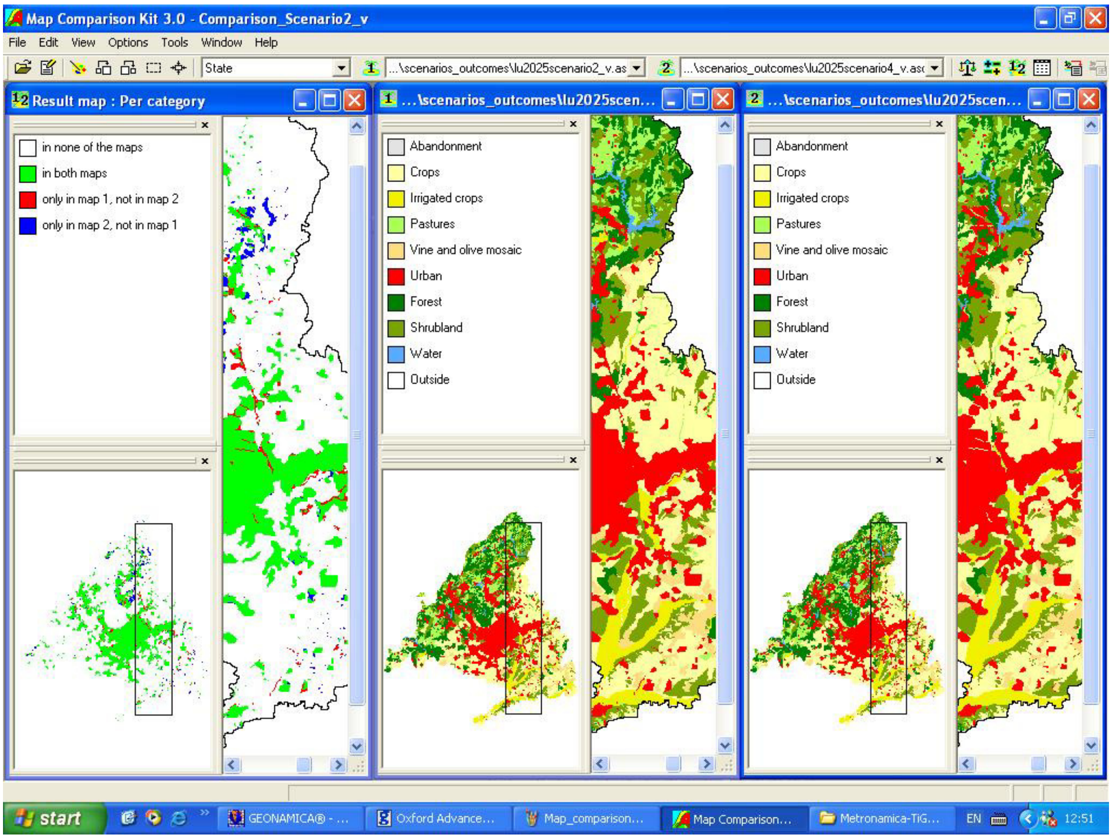
METRONAMICA run the simulation and we used MCK to develop the following map, afterwards. The result map for the forest category of land use allows to follow the evolution of the forest unit. This unit in the Scenario 4 is more focus on shaping all the riverbanks instead of occupying a large area of the riversides in the main rivers.

Map 9



Using again MCK, the screen dump compared the urban category for Scenario 2 and Scenario 4. The limitation of the urban development expansion nearby the riversides is aimed due to the implementation of this policy intervention (or so-called macro-scale constraint).

Map 10



Discussion and Prospects

The conceptual model developed by analysing the GIS data suggests that CAM, for all its rural nature, is actually an intensively utilised landscape. Regions that currently avoid intensive exploitation do so because they are protected by statute or unsuitable for development. Regulation in the region is largely competitive and consists, for the most part, of embargos on certain types of land-use. This confrontational approach to land planning creates strong conflicts of interest and is manifest in the form of three statistically distinguishable land-use conflict zones - an upland dynamic, an urban dynamic and an intensive agricultural dynamic.

The extension of transport infrastructure into the rural hinterland has produced 'ribbon development' along the roadways that fragments key landscape units. Attempts to encourage stakeholder participation runs into fairly clear political and economic conflicts of interest, sometimes compounded by demographic pressure. An ageing rural population is often only too willing to sell land for development. In this environment it has proven particularly difficult to move from a conflict-regulated system driven by short-term financial gain to a more co-operative strategy consistent with national and supra-national laws. Consequently, rates of convergence have been poor and compliance, particularly with natural resource legislation has been poor.

Our task in this project has been to help local and regional stakeholders move to a more participatory configuration in which power-politics and govern**ment** give way to sustainable development and effective govern**ance**. To this end, we acquired a thorough knowledge of land use conflicts in the region of Madrid. We learned that governmental plans are based on a presumption of urban expansion and a failure to take account of national and supra-national norms on sustainable development. The effect of the recent social and economical development of the *CAM* has been to marginalise the 'rustic land' and push sustainable agriculture so far down the list of priorities, it is hardly mentioned at all in the new legislation. The European project "Corine Land Cover 2000/1990" shows that CAM is the Spanish region that loses most agrarian or rustic land during the period of survey.

In the same way, different institutions from different spheres (such as the Ministry of Agriculture, Food and Fisheries; the Catalonia Government along with the local group *"Consell Comarcal del Baix del Llobregat"* and the Department of Land planning and Environment in the Basque Country Government) declared the relevant role of farming to maintain a balance in the territory. This statement issued a warning about the impact of these land use changes on key ecosystems and claimed they would result in loss of environmental quality and abandonment or degradation of agriculture.

The 'White paper of Agriculture and Rural Development for the *CAM*' (Autonomous Community of Madrid, 2005) makes only a passing reference to protecting sustainable agriculture, and that within the context of the Natura 2000 Network.

Although the role of stakeholders is well understood in the policy field, the absence of a supra-municipal or intermediary mechanism for policy-making implies the lack of commitment, solidarity and cooperation between stakeholders; especially between political insiders and outsiders. There is a clear need for some institutional control at this level to take account of the interaction between farming, landscape. By building this understanding into urban planning guidelines, we could re-establish the balance between rural and urban ecosystems.

The stakeholder engagement exercise described elsewhere was important for two reasons. It enabled us to build a measure of trust *and* to elicit concrete suggestions for policy initiatives that would permit the legitimate social and economic aspirations of stakeholders to be served while ensuring that key environmental resources would be sustained. It would be absurd to suggest that CAM should never be developed, but much more reasonable to suggest that the current break-neck rush to urbanisation can be allowed to continue. Some sort of legal and political oversight is clearly required to facilitate convergence.

This engagement process was so successful that we obtained a clear list of seven feasible policy interventions, suggested by stakeholders themselves, that were expected to help sustainable development in CAM. The two booklets (in Spanish and English) that described these options were well received and we found ourselves in the position of having to explore their likely effects.

It seemed unreasonable to argue that developers should undertake an environmental impact assessment, while we should float these interventions without doing an impact assessment of our own. Although TiGrESS had originally planned to build a conceptual model of CAM and supplement it with the booklet of interventions, we decided to ask the Commission for a two-month extension to build and evaluate a computational model.

That model fused empirical data with a knowledge of the transition processes derived from studies of fragmentation and trends in land-use change to build a two-level decision-support system for CAM. Here METRONAMICA served us particularly well. This system provides excellent facilities for exploring the interaction of macro-interventions at regional scale (top-down constraints) with micro-rules at cell scale (bottom-up responses that condition the transition potential between land use categories).

The final phase of our work was to use the model to undertake a pilot study of the most likely impacts of interventions on the region. Of course, we must emphasise that METRONAMICA simulates a presumption or theory about the region; it cannot be taken as a simulation of objective reality. Like all environmental impact assessment exercises, its predictions must be interpreted in the light of three possible sources of uncertainty.

1. Statistical uncertainty - different simulation runs may follow strikingly different routes because the micro-scale dynamics are stochastic (random decisions are made). Small variations can be amplified to create appreciable differences in macro-scale patterns.
2. Epistemological Uncertainty. The model simulates our understanding of regional dynamics. If that understanding is erroneous, the simulation outputs (even taking account of statistical variation) will be a poor guide to reality.
3. Innovation. It is possible (indeed, quite likely) that stakeholders will innovate - will perceive opportunities or threats that actually change the way they behave and so change micro-scale dynamics yet again.

It is perhaps rather normal to think of these sources of uncertainty as a 'problem' that must be resolved, but we are beginning to think of uncertainty, particularly innovation uncertainty as part of the solution. If it were impossible for humans to innovate, we could hardly hope to change the course of history in a way that facilitates sustainable development.

We must emphasise that these scenarios have not been explored in sufficient detail to give a complete understanding of statistical uncertainties. Much more simulation work is required. Only time will tell if our model is beset with epistemological uncertainty, we must wait and see how effective our predictions are as the CAM is developed into the future. However, in two respects we feel the Madrid model to have been a great success.

The scenarios were implemented and built by one of us (V H-J) in the course of a very few weeks. This was possible because of the excellent technical support provided by Maarten van Meulen and Inge Uljee at RIKS and because the METRONAMICA system is so easy to learn, provided the end-user has a clear understanding of the system involved.

The output produced by the METRONAMICA system is intuitively accessible. It takes the form of dynamic maps and simple graphics that can be incorporated into power-point presentations and shared readily with stakeholders. This intuitive accessibility is supplemented by the facility of producing useful statistical and data summaries that can be used to obtain quantitative outputs. In this way, the model has enables us to build bridges between the qualitative domain of stakeholder engagement and the quantitative demands of auditable impact assessments.

The next stage in the process must be to take these scenarios back to the stakeholder community for critical evaluation and revision. In this we are encouraged by the fact that stakeholders are now more strongly motivated to harmonise regional planning and make agreements for efficient participatory networks. This shift of emphasis from conflict to co-operation, though not yet fully consolidated with the inclusion of key developers, is a very encouraging development.

Already we are recognising that sensitive urban development may create a ready market for the products of sustainable agriculture. Forming a mosaic of sustainable farms and natural protected areas creates opportunities for tourism and recreation that enhances the value of housing (because it is located in a beautiful and interesting area) and provides opportunities for pluriactive farmers.

The simulation model, which provides accurate information by means of high-resolution outcomes to the stakeholders, can be used both as an educational tool and as an integrated Decision Support System (DSS) to support planners and policy-makers. Consequently, the model could be used by groups of stakeholders to search for innovative strategies for managing the region - strategies based on co-operation and trust, rather than on conflict and exclusion.

As an unexpected and very welcome spin-off from this work, the close collaboration of the Spanish team with the Polytechnic University of Madrid (UPM) and other stakeholders has led to moves to establish a ***sustainable land planning service*** for the region. We hope and expect that the data, models and other deliverables of the TiGrESS project will contribute materially to this work.

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