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Evaluation of Landscape Impacts and Land Use Change: a Tuscan Case Study for CAP Reform Scenarios

The study uses information from different sources and on different scales in an integrated set of models in order to analyze possible land use change scenarios arising in response to CAP reform. Five main steps were followed: (1) analysis of past land use changes, (2) multivariate analysis of future land use changes using a neural network time series forecast model (Multi-Layer Perceptron Method), (3) modelization of land use change demand (Markovian Chains Method), (4) allocation of the demand to define transition localization, (5) definition of policy scenarios.
The final stage is the comparison of CAP scenarios using a multicriteria decision making approach, in order to supply valuable information to policy makers regarding the possible local effects of key direction changes in CAP.

Keywords: *Landscape impact, CAP reform, Land use change, Neural network, Spatial analysis, MCDM*

1. Introduction

Agriculture and related land use changes continuously in response to the Common Agricultural Policy (CAP) reform and to market forces, and general awareness has arisen about the effects of these changes (Bernetti *et al.* 2006). The development of the agricultural sector has included structural transformation of farms, as well as land use and land cover changes (LULCC), to meet market requirements in terms of economic efficiency. These leading forces have trapped agricultural land between the phenomena of specialization/intensification and abandonment of higher cost, less competitive production areas. These two distinct phenomena are taking place in the context of the complex interaction between biophysical and socio-economic factors operating at various levels and driving land use pattern modifications with implications for the multifunctionality of agriculture.

International modelling studies of change of land use have highlighted two important facts: the role of models is not to provide an exact prediction of what is going to happen in the future, but to provide very different long-term scenarios that can be used to evaluate short-term options. The complexity of the socioeconomic, geographical, geomorphologic and ecosystemic problems has led more and more frequently to the implementation of approaches that integrate analysis models that work synergistically.

The present study allows the combination of information from different sources and on different scales, using an integrated set of models with the objective of analysing the possible land use change scenarios arising in response to CAP reform.

Using the Land Change Modeller (LCM) approach, the study tries to integrate the principles of different models in a framework that enables the consideration of the macroeconomic role of land policies accomplishing a very high definition of results through a sufficiently flexible methodology. The LCM approach proceeds through separate but intertwined stages: the identification of significant land use transition in a specific time period by cross-tabulation; a multivariate analysis of future transition potential localization using a neural network time series forecast model; the modelling of the future demand for land use change by the Markov chains method applied to transition probabilities; finally, the allocation of the demand for change in order to define the geographical localisation of transitions using a multi-objective programming method for the allocation of land resources among a range of use classes. The choice of using an approach that is based on three methodologies can be critical, as it may result in the emphasising of errors and inaccuracies. On the other hand, the multidisciplinary nature of land-cover change modeling is paralleled by modularity in the models themselves. In general, modularity may help facilitate modeling land-cover change by assigning a particular disciplinary aspect of the model to a separate module. The complexity of a model is also related to model modularity. Complex models typically involve the interaction of multiple parameters, and their creation and validation can be facilitated by using multiple modular components; for example, modularity allows different processes to run at different time steps, different actors can be modeled simultaneously in different modules, and differences in their decision-making horizons can be incorporated by varying the time step of different modules. There is a strong need for a modular approach to land-use change models that includes the relative effects of different social drivers – such as demography, technology, economy, political and social institutions, culturally determined attitudes, beliefs, and behavior, information and its effect on land-use change – all in the context of space, time, and scale (Agarval *et al.* 2002).

According to literature, the CAP scenario construction is based on two key policy dimensions that indicate the presence/absence of the most significant policy factors.

The final stage of the study is the comparison of CAP scenarios using a multicriteria decision making approach. The results are intended to supply valuable information to policy makers regarding the possible local effects of key direction changes in CAP.

2. The Land Use Change Model

The recent developments in the LULCC models sector are linked strongly to the diffusion of Geographic Information System technologies. Bibby and Sheperd (Bibby and Sheperd 2000) examined the most important and recent models with a focus on their strengths and weaknesses.

This study uses the land change modeller (LCM) approach. LCM is a macro level land use change approach that was proposed by Eastman (2005, 2006a, 2006b). The application of the LCM approach assumes that the causes of land use changes belong to two categories: the local territory endogenous change trends (drivers) that can be extrapolated by the analysis of phenomena that occurred in a significant time period; and the exogenous changes caused by the implementation of long-term land policies and by constraints and incentives. Thus, the proposed approach tries to integrate many of the principles of the models that were introduced in the previous paragraph: the macroeconomic role of land policies that is emphasised in macro-level models, the high definition of cellular and neural network models and the flexibility of knowledge-based models.

The LCM method models land use changes by a succession of stages in which specific analysis and forecast models are applied.

Stage 1. Identification of significant transitions, which is achieved by comparison of changes that occurred in a specific time period. Two land use maps at two moments in time (t_1 and t_2) are cross-compared (cross-tabulation). A transition matrix with the general structure shown in Tab. 1 (Pontius et al. 2004) is used for this stage. In the Table, $S_{i,j}$ indicates the land that shifts from use category i to use category j; the values on the matrix diagonal indicate the persistence; row total S_{i+} indicates the land in category i at time 1, and column total S_{+i} indicates the land at time 2; gross losses for each category are obtained as the difference between total values at time 1 and persistence values, while gross gains are obtained as the difference between total values at time 2 and persistence values. The last row of the matrix shows net and total changes.

Table 1. Structure of a transition matrix.

		Time 2						Losses
		Land use 1	Land use 2	…	…	Land use n	Total time 1	
Time 1	Land use 1	$S_{1,1}$	$S_{1,2}$			$S_{1,n}$	S_{1+}	$L_1 = S_{1+} - S_{1,1}$
	Land use 2	$S_{2,1}$	$S_{2,2}$			$S_{2,n}$	S_{2+}	$L_2 = S_{2+} - S_{2,2}$
	…							…
	…							…
	Land use n	$S_{n,1}$	$S_{n,2}$			$S_{n,n}$	S_{n+}	$L_n = S_{n+} - S_{n,n}$
	Total time 2	S_{+1}	S_{+2}			S_{+n}		
Gain		$G_1 = S_{+1} - S_{1,1}$	$G_2 = S_{+2} - S_{2,2}$	…	…	$G_3 = S_{n+} - S_{n,n}$		
Net change Gain – losses		$G_1 - L_1$	$G_2 - L_2$	…	…	$G_3 - L_3$		
Total change Gain + losses		$\lvert G_1\rvert + \lvert L_1\rvert$	$\lvert G_2\rvert + \lvert L_2\rvert$	…	…	$\lvert G_3\rvert + \lvert L_3\rvert$		

Stage 2. Multivariate analysis of future transition potential localization using a neural network time series forecast model. Neural networks were initially proposed for the ranking of land use patterns from satellite images, and were later applied successfully to land use change models (Li and Yeh 2002; Tang et al. 2005; Pijankosky 2005). Neural networks are non-linear multivariate methods that simulate the way a human brain analyses complex issues. Multi-layer perceptrons (MLPs) with a back-propagation learning algorithm are implemented in the present work.

The implementation of neural networks to calculate the transition potential can be summarised in the following procedure (Fig. 1). In the system initialisation, the pixels that relate to the transition examined (i.e. from arable lands to urban areas) that occurred from 1990 to 2000 are assigned randomly to one of two groups: the training set and the testing set.

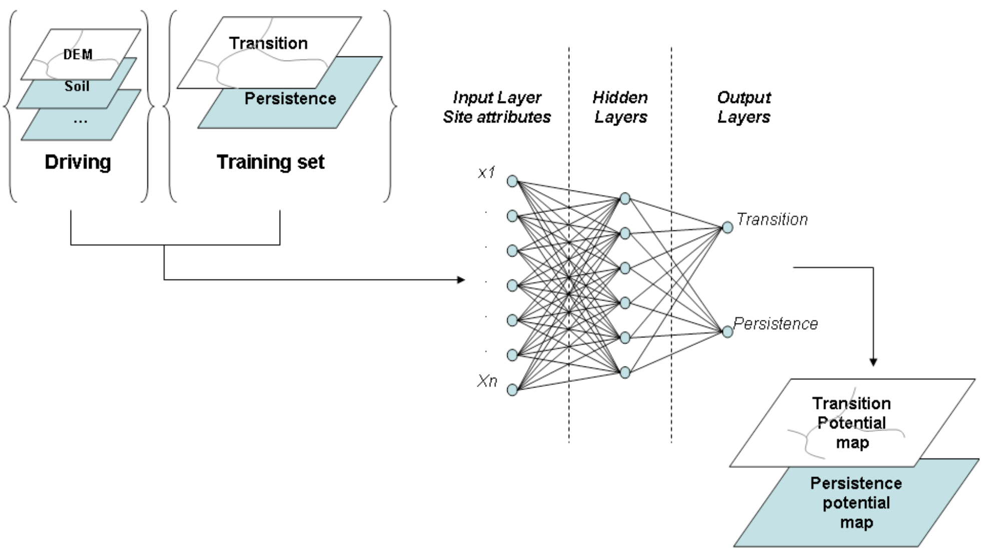
The forward pass involves the training set and consists of the identification of the input variables, on the basis of the hypothesis that the probability of transition from a land use to another is determined by the geographical characteristics and the location factor. These variables derive from the geographical and geo-statistical elaborations of a geographic information system and can be formalised as follows:

$$X = x_1, x_2, \ldots, x_n \tag{1}$$

Every variable is associated with a neuron in the input layer and is normalised using:

$$x_i' = (x_i - \min)/(\max - \min) \tag{2}$$

Figure 1. Multi-layer perceptron network applied to land use change analysis.



In the hidden layer, the signal that is received by neuron *j* in the hidden layer for pixel *k* is calculated as follows:

$$net_j(k) = \sum_i w_{i,j} x_i^{'}(k) \tag{3}$$

where $net_j(k, t)$ is the signal that is received by neuron *j*, and $w_{i,j}$ is the weight between the input layer *I* and the hidden layer *j*. The output layer has 2 neurons that correspond to 2 possible significant states (1 = transition, 2 = permanence of the pixel); the neuron *l* generates a value that indicates the transition probability. Transition probabilities can be calculated using a sigmoidal function (a sigmodial function is used to represent the non-linearity of each node):

$$P(k, l=1) = \sum_j w_{j,l} \frac{1}{1+e^{net_j(k,t)}} \tag{4}$$

The transition result file contains values ranging from 0.0 (no likelihood of change) to 1.0 (highest likelihood of change) and it was evaluated by comparing the test set of cells that were observed to undergo transition with the cell with the highest likelihood of transition based on the model. The error is spread backward in order to correct the weight set according to the "delta rule" (see Rumelhart *et al.* 1988). The new weights are then introduced in a new forward process. The training set is presented to the network iteratively until a stable set of weights is achieved and the error function is reduced to an acceptable level.

Stage 3. Modelling the future demand for land use change by the Markov chains method applied to transition probabilities. Through the use of a GIS system a transition matrix can be calculated. A Markov chain is made of s, a vector of the distribution of land use classes at time t, and A(τ), a matrix of transition probabilities from land use u to land use u′ in a given time interval (τ).

$$s_{t+\tau} = A(\tau) s_t \tag{5}$$

For the calculation of transition probabilities, it is necessary to have a map of land use classes at time t + τ. The maximum likelihood estimates of probabilities of change from one land cover to another during time interval τ are:

$$m_{u,u',t} = \frac{n_{u,u'}}{\sum_{u'} n_{u,u'}} \tag{6}$$

where $m_{u,u',t}$ are the transition probabilities from land use *u* to *u′* in time interval *t*, and $n_{u,u'}$ is the total number of transitions. For any forecast that regards time intervals different from that between the two maps, it is possible to use the following normalization (see Li and Ye 2002 and Esatman 2005, 2006 and 2006b for more details):

$$
\begin{cases}
m_{u,u'} = 1 - e^{(\ln(1-p_{u,u',y}))/\tau} & \text{when } u \neq u' \\
m_{u,u'} = 1 - \sum_{u'} p_{u,u'} & \text{when } u = u'
\end{cases}
\tag{7}
$$

where t is expressed as a fraction of the desired time-scale.

Stage 4. Allocation of the demand for change in order to define the geographical localisation of transitions. A multi-objective programming method for the allocation of land resources among a range of use classes is used at this step. Given: $x_j^{u' \to u'}$ is the i^{th} pixel that shifts from land use u' to land use u; $P_i^{u' \to u'}$ is the transition potential of the i^{th} pixel; $S_{t+\tau}^{u,k}$ is the land demand for use u at time t + t for scenario q; and the allocation of changes is given by the following integer numbers model:

$$
\begin{aligned}
& MAX \sum\nolimits_{k,u} x_k^{u' \to u} \cdot P_i^{u' \to u} \\
& s.t. \\
& \sum\nolimits_u x_k^{u' \to u} = 1 \\
& \sum\nolimits_k x_k^{u' \to u} \leq S_{t+\tau}^{u,q} \quad \forall u \\
& with \\
& S_{t+\tau}^{u,k} = \sum_{u'} m_{u,u'} \cdot S_t^{u,k}
\end{aligned}
\tag{8}
$$

The total structure of the model is shown in Fig. 2.

3. The Case of Tuscany

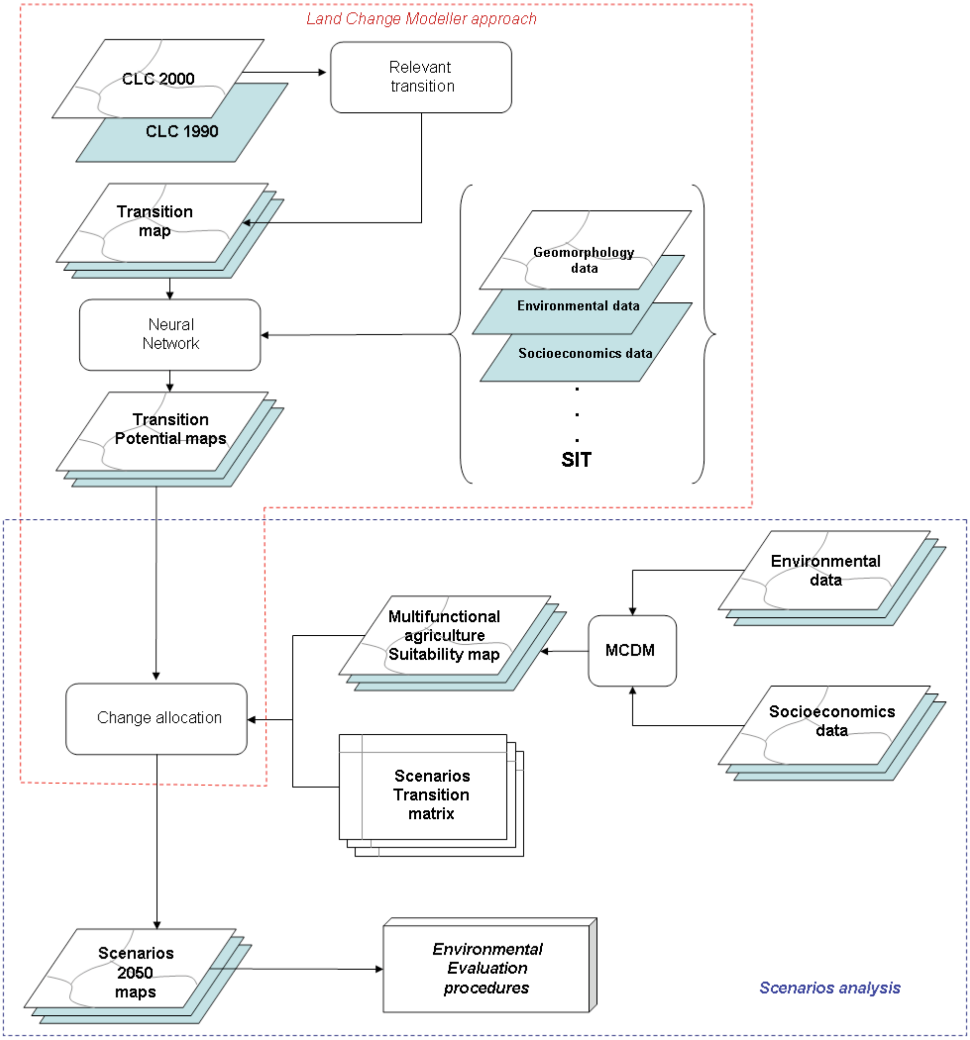
3.1. The study area

Tuscany (Italian: Toscana) is one of the 20 Regions of Italy (NUTS2 administrative divisions). Agricultural and forestry land use are spread out over the Region, covering around 1,943,699 ha (ISTAT 2000 data), 84.5% of total surface. The structure of the local agricultural production system is extremely diverse. Agricultural activities show different pressure levels on the environment, determined mainly by farm type and the related production system. All of these factors have strong effects on the landscape characteristics and values, as well as the land use and land cover pattern. In the last ten years, the agricultural area has decreased by around 7.5% ha, most of which are used for arable crops (ISTAT 1990-2000 data).

3.2. The Transition Matrix

Initial and final land use for the construction of the transition models derive from the CORINE Land Cover database for the year 2000. Database categories

Figure 2. A representation of the model structure.



were merged in order to have a wide range of possible transitions without losing any of the information content. The classes that were used are:

- Urban.
- Arable land.
- Permanent crops.
- Heterogeneous agricultural areas.
- Natural and semi-natural areas.
- Water.

The chosen detail level for the rasterised layers is 75 metres, which is a very high level of detail, suitable for analysing changes in the landscape at the local level.

The 1990 and 2000 maps are compared to produce a cross-tabulation matrix that shows the surface of the landscapes for each transition (Tab. 2). The transition matrix shows that heterogeneous agricultural areas experienced the greatest loss (48% of total loss) of landscape, and urban areas experienced the largest gain (about 41%). Heterogeneous agricultural areas and arable land had the largest total change.

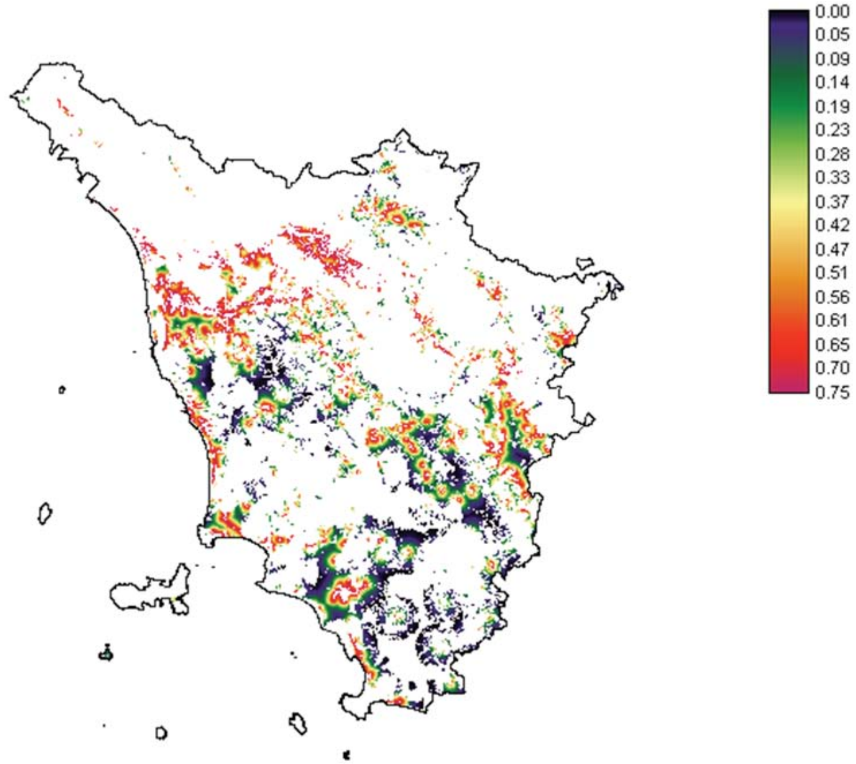
Table 2. Transition matrix (hectares).

		2000							
	Land Use	Urban	Arable land	Permanent crops	Heterogeneus agricultural areas	Natural and seminatural areas	Water	Total 1990	Losses
1990	Urban	152,185	0	0	0	0	0	152,185	0
	Arable land	5,018	945,440	2,571	2,295	2,003	331	957,658	12,218
	Permanent crops	979	1,379	218,611	1,849	713	0	223,531	4,920
	Heterogeneous agricultural areas	9,180	883	4,608	549,591	3,735	24	568,021	18,430
	Natural and semi-natural areas	483	1,300	265	427	2,157,414	380	2,160,269	2,855
	Water	0	0	0	0	0	24,715	24,715	0
	Total 2000	167,845	949,002	226,055	554,162	2,163,865	25,450	4,086,379	38,423
	Gain	15,660	3,562	7,444	4,571	6,451	735		
	Net change	15,660	-8,656	2,524	-13,859	3,596	735		
	Total change	15,660	15,780	12,364	23,001	9,306	735		

Grey shade, permanence; underline, significant transition.

The next step in analysing the matrix is to examine the off-diagonal entries and to identify the significant transition. This stage is very critical because it allows minor transitions that may be the result of map error or may be considered not significant enough for the purpose of the study to be filtered out. In order to have a sufficient number of observations in the training and testing sets, transitions of 3000 pixels (1700 hectares) or more are considered significant. As a matter of fact, transitions of less than 3000 pixels did not help in the identification of a set of significant dependent variables on the basis of Cramer's V test. The following transitions were taken into account:

Figure 3. A transition potential map of change of land use from arable to urban areas.



- from arable land to urban areas;
- from arable land to permanent crops;
- from arable land to heterogeneous agricultural areas;
- from arable land to natural and semi-natural areas (abandon);
- from permanent crops to heterogeneous agricultural areas;
- from heterogeneous agricultural areas to urban;
- from heterogeneous agricultural areas to permanent crops;
- from heterogeneous agricultural areas to natural and semi-natural areas (abandon).

These transitions cover over 81% of the total changes of the Tuscan landscape.

3.3. The Neural Network Analysis

The next step is the elaboration of transition potential maps (see Fig. 3 for an example). The location factors that were assumed to be determinants of the land use change are derived from a wide range of different data sets. Tab. 3 gives all of the variables included in the analysis.

Table 3. Location factor and variables list.

Location factor	Variable	Source
Accessibility	Road distance Urban land cover distance	Road map CORINE Land Cover
Geomorphology	DEM Slope	Digital Elevation Model
Ecopedology	Evidence likelihood* of climatic data Evidence likelihood of pedology Evidence likelihood of aspect	Climatic data Pedology map Digital Elevation Model
Rural district	Vineyards distance Evidence likelihood of vineyards region	CORINE Land Cover DOC and DOCG areas
Urban policy	Evidence likelihood common urban policy	Urban plan
Transition from agricultural land to forest by natural forest colonization	Focal function of forest neighbourhood Distance from existing natural areas	CORINE Land Cover
Land suitability for agroforestry transformation	Forest ecotones River ecotones	CORINE Land Cover Idrological map
Socioeconomics models	Farm household index of propensity for: a. high-quality products; b. agroforestry.	Small area georeferenced census microdata

* The procedure looks at the relative frequency of pixels belongings to the different cathegories of that variables within areas of changing.

To ensure that the neural network prediction model will not be confused by irrelevant information during the learning stage, we reduce the number of causal variables. This is done by performing Cramer's V coefficient test (Zembowicz and Zytkow 1996) for each causal variable, and those with $V \geq 0.15$ are selected.

The variable used in each transition model is shown in Tab. 4. The goodness of fit was evaluated by comparing the neural network result and the CLC 2000 land use for each category of land use. All the models appear to be acceptable.

Together with the transition potentials that were calculated by the MLP procedure, it was necessary to identify new transition potential maps, related to evolution of the agricultural sector that had not occurred in the past, caused by new actions of the Common Agricultural Policy (CAP), especially those related to the promotion of high quality and typical products and to the passage to a system based on single farm payments. The new transitions are:

Table 4. Variables of the transition potential models.

Transition	Variables	Testing and training set (number of pixels)	Error	Accuracy rate (%)
From arable land to urban areas	Roads distance Urban land cover distance Elevation Slope	2,470	0.004007	75.2
From arable land to permanent crops	Evidence likelihood of climatic data Evidence likelihood of pedology Evidence likelihood of aspect Elevation Slope Vineyards distance Evidence likelihood of vineyards region	1,285	0.005378	78
From arable land to heterogeneous agricultural areas	Evidence likelihood common urban policy Slope Elevation	1,127	0.003876	92.64
From arable land to natural and semi-natural areas	Focal function of forest neighbourhood Distance from existing natural areas Elevation Slope Evidence likelihood of climatic data Evidence likelihood of pedology	1,001	0.005861	76.4
From permanent crops to heterogeneous agricultural areas	Urban land cover distance Roads distance Evidence likelihood of climatic data Elevation slope	922	0.00701	77
From heterogeneous agricultural areas to urban	Roads distance Urban land cover distance Slope elevation	4,556	0.003237	71.6
From heterogeneous agricultural areas to permanent crops	Evidence likelihood of climatic data Evidence likelihood of pedology Evidence likelihood of aspect Elevation Slope Vineyards distance Evidence likelihood of vineyards region	2,294	0.004	78.5
From heterogeneous agricultural areas to natural and seminatural areas	Focal function of forest neighbourhood Distance from existing natural areas Elevation Slope Evidence likelihood common urban policy	1,867	0.0045	78.2

- from arable land to agricultural high-quality production;
- from arable land to agroforestry;
- from heterogeneous agricultural areas to high-quality production;
- from heterogeneous agricultural areas to agroforestry.

It was not possible to use the MLP procedure for these transitions, as there was no series of cases in the past. Four suitability maps were assessed for each transition, using a geographical multicriteria analysis procedure (Pontius and Schneider 2001; de Nijs *et al.* 2004). The suitability maps (Fig. 4) were obtained by a combination of socioeconomic and territorial variables that indicate farmers' propensity to redirect their farms toward high-quality productions and agroforestry interventions for environmental improvement. In general, a multicriteria evaluation model can be written as $S = f(x_1, x_2, \ldots, x_n)$, where S is the suitability evaluation index and xn are the factors that determine the evaluation.

The methodology that was used in the construction of suitability maps was:

- Definition of the evaluation's objective.
- Identification and evaluation of criteria.
- Aggregation of criteria.

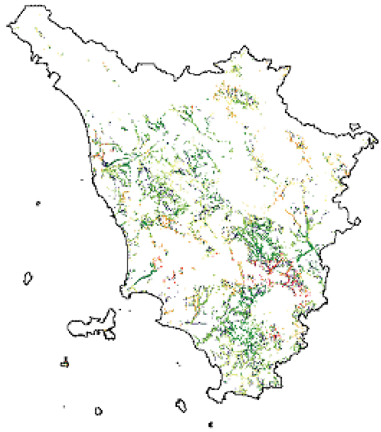
In the proposed method, the evaluation's objective is the potential of land for each transition; the different criteria are chosen on the basis of actual territory characteristics – social, geographical, environmental – which can influence the transformation and the evaluation of effects of criteria is carried out using *fuzzy* functions (Bernetti e Fagarazzi 2002).

The aggregation of criteria has to be carried out using different logical-mathematical operators relating to the examined issue. The family of aggregation operators that is both complete and able to modelise spatial evaluation issues in the most efficient way is based on fuzzy logic; in the application, the following aggregation operators were used:

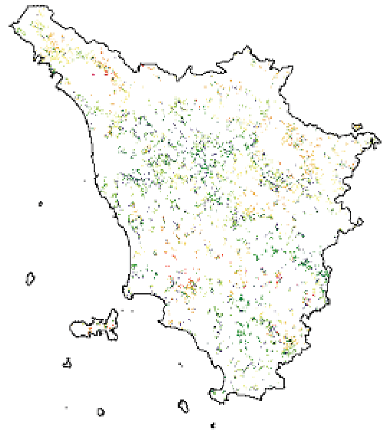
- *media*: $\mu(Sg^s) = \frac{1}{n} \sum \mu(x^c)$ with $\mu(Sg^s)$ fuzzy evaluation of socio-economic and geographical factors for the transition toward *s'* and $\mu(x^c)$ of criterium *c* with *c = 1,2,…C*^{s} criteria that influence the transition *s'*. It is the operator with a more common use.
- *fuzzy*-AND: $\mu(Sg^s) = (1-\gamma) \cdot \frac{1}{n} \sum \mu(x^x) + \gamma \cdot \min\left\{\mu(x^c)\right\}$ Parameter γ is called compensation degree. With $\gamma \to 1$, the operator tends toward the logic AND, with $\gamma \to 0$ the operator tends toward the average value, while values between 0 and 1 give intermediate results.
- *fuzzy*-OR: $\mu(Sg^c) = (1-\gamma) \cdot \frac{1}{n} \sum \mu(x^c) + \gamma \cdot \max\left\{\mu(x^c)\right\}$ The characteristics are similar to the *fuzzy*-AND.

Flow charts for the geographic models are shown in Figs. 5 and 6.

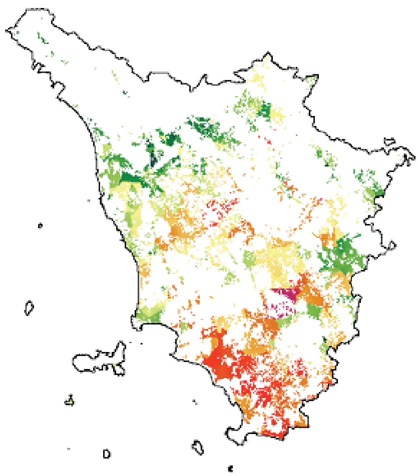
Figure 4. Suitability maps.



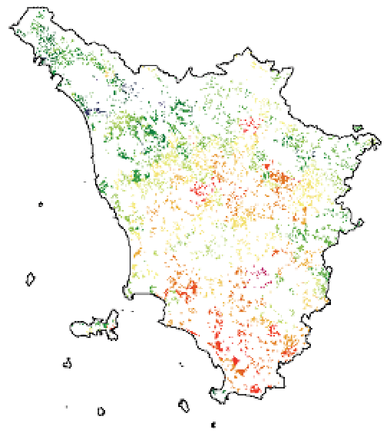
Suitability map for transition from arable land to agroforestry



Suitability map for transition from heterogeneous agricultural areas to agroforestry



Suitability map for transition from arable land to high-quality production



Suitability map for transition from heterogeneous agricultural areas to high-quality production

4. Scenario Construction

4.1. The Direction of the Common Agriculture Policy as a Basis for the Construction of Scenarios

The choice of scenarios for this study is based on the observation of the evolution of CAP and was the result of the definition of the main aspects of the chan-

Figure 5. Suitability flow chart for conversion to agroforestry.

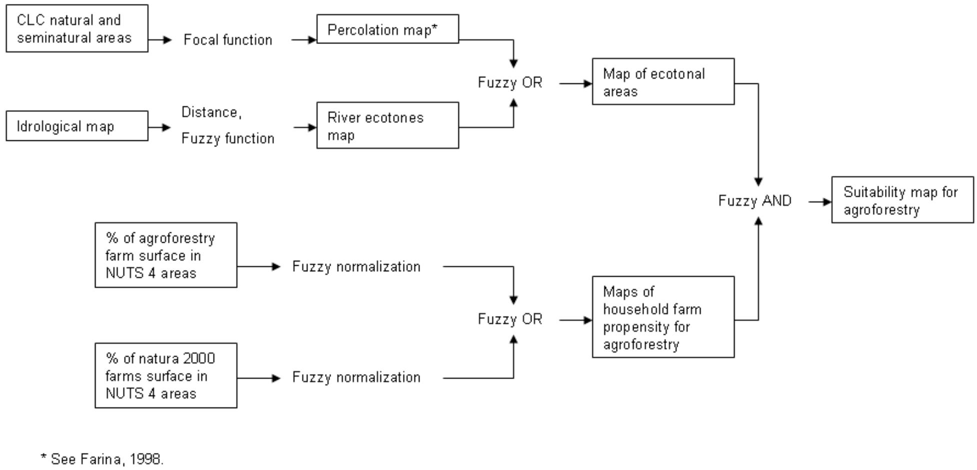
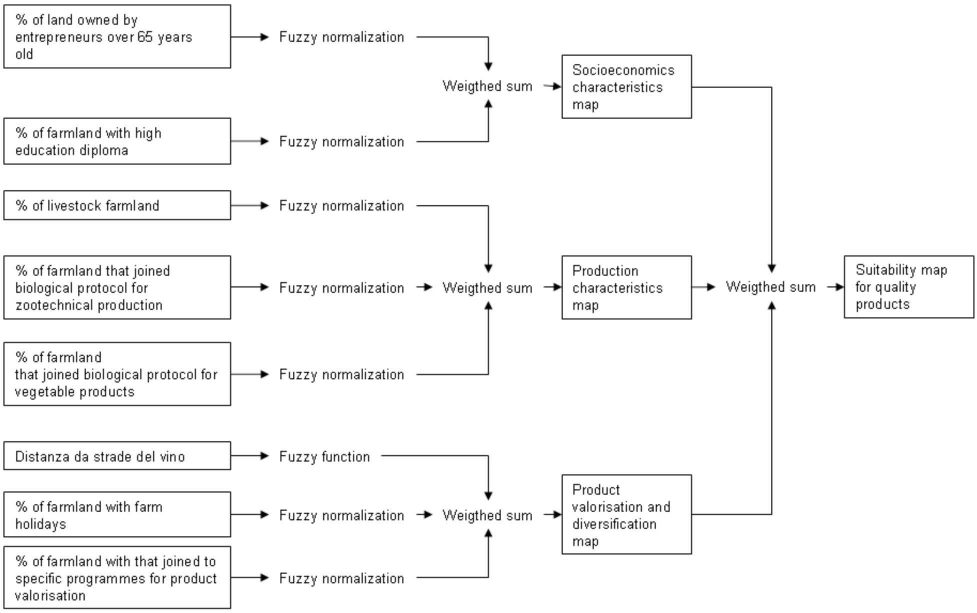


Figure 6. Suitability flow chart for conversion to high-quality production.



ges under study. Starting with *Agenda 2000*, CAP has progressively oriented its objectives to new, pressing issues, focusing on improving the competitiveness of Union products, on guaranteeing the safety of agricultural products for the consumers and on employment and environmental issues – by including environmental objectives in its tools – and thus marking an important strategic shift from the past and starting an important period of redefinition of the equilibria between rural activities and territory.

The CAP Mid Term Review, which found its formalisation with the Luxemburg deal in June 2003, represents a strong sign of continuity of the *Agenda 2000* policy, moving from the same principles and expanding its scopes and actions. The importance and magnitude of MTR, though, make it a reform in its own right. The MTR promotes the following new objectives for CAP:

- supporting a multifunctional agriculture that respects the environment and landscapes, that eases the preservation of biodiversity and grants a rational development of agricultural productions;
- granting adequate life conditions and fair income levels for rural communities;
- regulating and stabilising the markets to prevent crises;
- granting the security of supply;
- granting fair prices for the consumers;
- supporting food quality and safety.

In order to achieve a more efficient policy in terms of both environmental and financial sustainability, and given the pressing issues connected with the enlargement of the EU, the reform provides for the following specific tools:

- single farm payments, subject to the cross-compliance principle;
- market policies revision and dynamic modulation of payments in order to increase the funds for the CAP Second Pillar;
- a new system of farm audit and new rural development actions that are intended also for the protection of consumers.

The decoupling of payments and their subsequent severed link to production levels towards the institution of a single farm payment is a core tool in such a context and it requires the revision of Common Market Organisations (CMOs) role, which is now limited to additional actions for strategic products and crops. In particular, the exceptions to the decoupling principle are conceived with regard to the possibility of continuing agricultural activities in less-favoured rural areas that are subject to high rates of depopulation (Fischler 2003).

In order to help farmers respond better to the necessities linked to environmentally friendly activity and production, the reform has introduced a new form of farm audit. This system is intended to help in both environmental and social aspects of sustainability issues.

The steps that have redefined agricultural policy in Europe have directed attention towards non-production aspects of agriculture, marking a turning point in the allocation of resources in the direction of needs that cannot be matched on the market. Environmental and social functions of agriculture are considered of pivotal importance now more than ever, and the shift in resource allocation is justified by the impossibility of accounting for those functions in a progressively more liberalised market scenario.

4.2. Elaboration of Scenarios

The aim of the scenario analysis in this work was to determine the results that can be achieved by certain strategic lines of agricultural policy. For this kind of scenario analysis, the authors (Wack 1985; van der Heijden 1996; Ogilvy and Schwartz 1998; Westhoeck *et al.* 2006) recommend choosing few and very different scenarios. It is very important to expand the results of the simulation by relating them to a time interval that is suitable to show the effect of all possible changes.

There are many agricultural policy driving forces that can be significant in the long term, but it is not efficient to try to build scenarios that relate to all these forces, as this would make the analysis and evaluation process complicated and uncertain. This is the reason why, according to the literature (Ogilvy and Shwartz 1998; Westhoeck *et al.* 2006), it is better for the scenario construction to be based on two key dimensions that are chosen to indicate the presence/absence of the two most relevant factors. By using these dimensions, it is possible to build a 2×2 matrix that can be used as a basis for the definition of the parameters that characterise the scenarios. According to Ogilvy and Schwartz (1998), using this approach leads to scenarios that are logically and deductively very different.

Given the evolution in the formalisation and implementation of agricultural policy that was outlined in paragraph 4.1., the main dimensions for the scenario construction were chosen as follows (Fig. 7):

- the achievement of a multifunctional agriculture as opposed to a model of agriculture that is based entirely on market rules in a globalisation context;
- the complete decoupling of payments and no income support as opposed to the link between payments and production levels and income support.

Multifunctionality, as deriving from the debate from Agenda 21 to Agenda 2000, is intended as the positive "goods" that agriculture can produce beyond the commodities that farmers sell in the marketplace. These goods can be defined quite broadly, but generally include contributions to biological diversity, clean water and air, bioenergy, and landscape values.

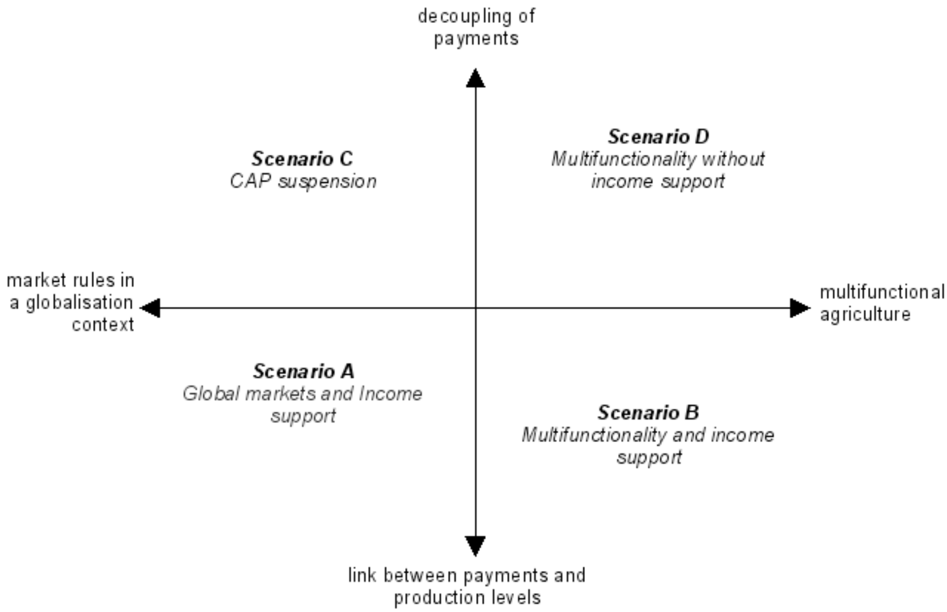
The scenarios were named (Fig. 7):

Scenario A: global markets and income support.
Scenario B: multifunctionality and income support.
Scenario C: CAP suspension.
Scenario D: multifunctionality without income support.

The scenarios were constructed by long-term simulations (2050) in order to consider the effects of both socio-economic and European agricultural policy cycles (Westhoeck *et al.* 2006).

In the case of stationary scenarios (scenario A), the Markov chain is employed to reckon the global transition probabilities. Transition to high-quality products or agroforestry is not allowed.

Figure 7. Development of scenario-relevant dimensions.



Models for potential transition toward high-quality cultivations and environmental improvement interventions were used for scenario B. In scenario C, the Markov transition probability matrix was modified (see Jenerette and Wu 2001; Coppedge *et al.* 2007; Garcıa-Frapolli *et al.* 2007) with econometric linear programming aggregated farm sector model (see Hazel and Norton 1986 for more details) forecasts that allowed assessment of the final demand for land use for urbanisation (Yen 2007; Lopez 2001) and abandoned agricultural lands as a consequence of negative net income deriving from the interruption of income support for farmers. Transition to high-quality products or to agroforestry is not allowed. The transition matrix used for scenario C was used also for scenario D, and the suitability models for transitions toward high-quality products and environmental improvements were implemented. The characteristics of each scenario are given in Tab. 5.

5. Results

5.1. Scenario Results

The results of the land use change simulation are shown in four maps with 75 metres resolution for the whole Tuscan territory. These maps, thanks to their high resolution, are able to give important information regarding landscape change trends that can be used in support of territorial policies at the regional/local level (Fig. 8).

Table 5. Scenario characteristics.

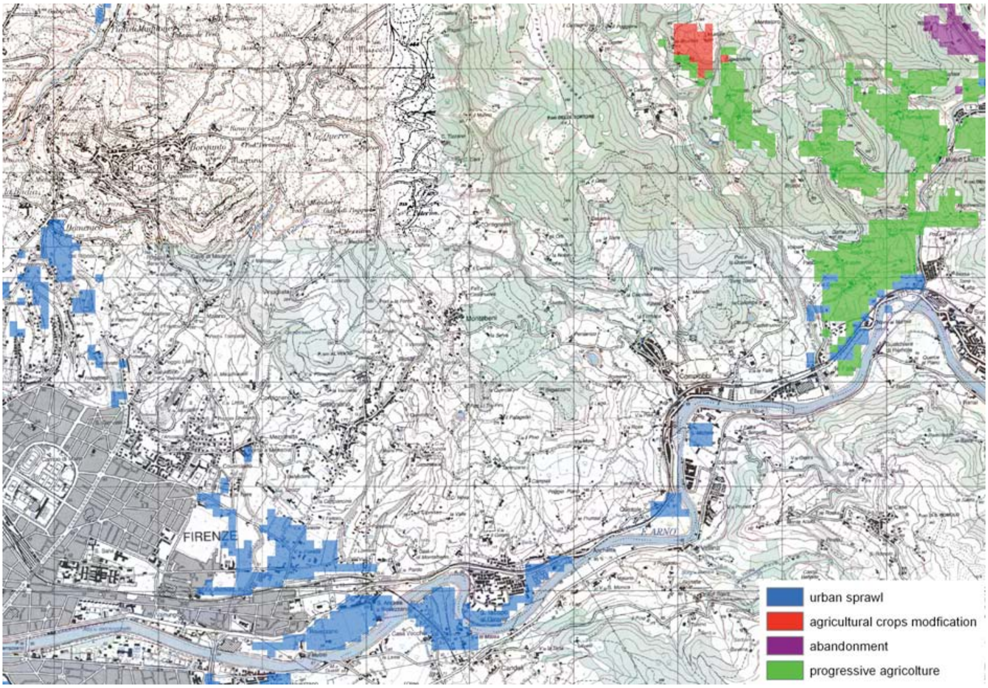
	Scenario A: global markets and income support	Scenario B: multifunctionality and income support	Scenario C: CAP suspension	Scenario D: multifunctionality without income support
Abandoned agricultural lands, converted spontaneously to nature	Markov chain transition matrix	Abandoned agricultural land owned by farmer with net income with support < 90 € /day (calculated by census micro-data)	Abandoned agricultural land owned by farmer with net income without support < 90€ / day (calculated by census micro-data)	Abandoned agricultural lands owned by farmer with net income without support < 90 € / day (calculated by census micro-data)
Urban areas expansion	Markov chain transition matrix	Urban expansion according to urban planning	Urban expansion according to MOSUS project results (Prieler, 2005)	Urban expansion according to MOSUS project results (Prieler, 2005)
New agri-environmental cultivations	Not present	Suitability map	Not present	Suitability map
New high-quality cultivations	Not present	Suitability map	Not present	Suitability map

As an overview of the results, transitions have been combined in order to underline the main impacts of land use change, and the combinations were defined as follows:

- urban sprawl: from arable land and from heterogeneous agricultural areas to urban;
- crop transformation: from arable land to permanent crops, from arable land to heterogeneous agricultural areas, from permanent crops to heterogeneous agricultural areas, from arable land to permanent crops and from heterogeneous agricultural areas to permanent crops;
- abandonment: from arable land to natural and semi-natural areas and from heterogeneous agricultural areas to natural and semi-natural areas;
- Multifunctional agriculture: from heterogeneous agricultural areas to agroforestry, from arable land to high-quality production, from permanent crops to high-quality production, from heterogeneous agricultural areas to high-quality production and from arable land to agroforestry.

The most striking results for each scenario are summarized on the basis of these combinations in Tab. 6 and in Fig. 9.

Figure 8. Small-scale transition map for scenario D near Florence.



Scenario A: Global markets and income support

This is the scenario with the lowest impact on the Tuscan landscape. Keeping the agricultural policies as they were in the past reduces both abandonment and cultivation changes in Tuscan farms. Cultivation is abandoned in economically less favoured areas on Tuscan mountains and in the South of the region, and is caused mainly by low local productivity and by depopulation. Crop changes consist mainly of transitions towards permanent crops and are concentrated in the most important areas of viticulture (the Chianti region and the Siena province). The biggest change is in urban areas, even though it is less evident than in other scenarios.

This scenario starts to reveal two trends that give valuable information about the policy impacts on land use: the change towards permanent crops and urban areas. It will be explained later (similar results are obtained for all the scenarios in this simulation) that these trends seem to be less influenced by the direction CAP can follow, with urban areas expanding according to local urban regulation and viticulture, especially in the area that can be considered one of the main centres of Italian wine-making sector, expanding as a result of market-oriented choices that are influenced only partly by agricultural policy.

Table 6. Scenarios results (hectares).

Transformation	Scenario			
	A	B	C	D
From arable land to urban areas	15,000	13,665	19,965	19,965
From heterogeneous agricultural areas to urban areas	25,467	23,348	33,883	34,102
From arable land to permanent crops	7,420	6,779	6,779	6,779
From heterogeneous agricultural areas to permanent crops	12,313	11,346	11,346	11,346
From arable land to heterogeneous agricultural areas	6,513	5,196	5,979	5,979
From permanent crops to heterogeneous agricultural areas	5,137	294	4,730	3,236
From arable land to abandonment	645		80,125	42,496
From arable land to agroforestry		80,125		15,797
From heterogeneous agricultural areas to abandonment	10,848		53,366	23,524
From heterogeneous agricultural areas to agroforestry		53,366		17,093
From arable land to high-quality production		113,208		60,612
From permanent crops to high-quality production		1,936		1,494
From heterogeneous agricultural areas to high-quality production		40,446		14,346
Total	83,343	349,709	216,173	256,769

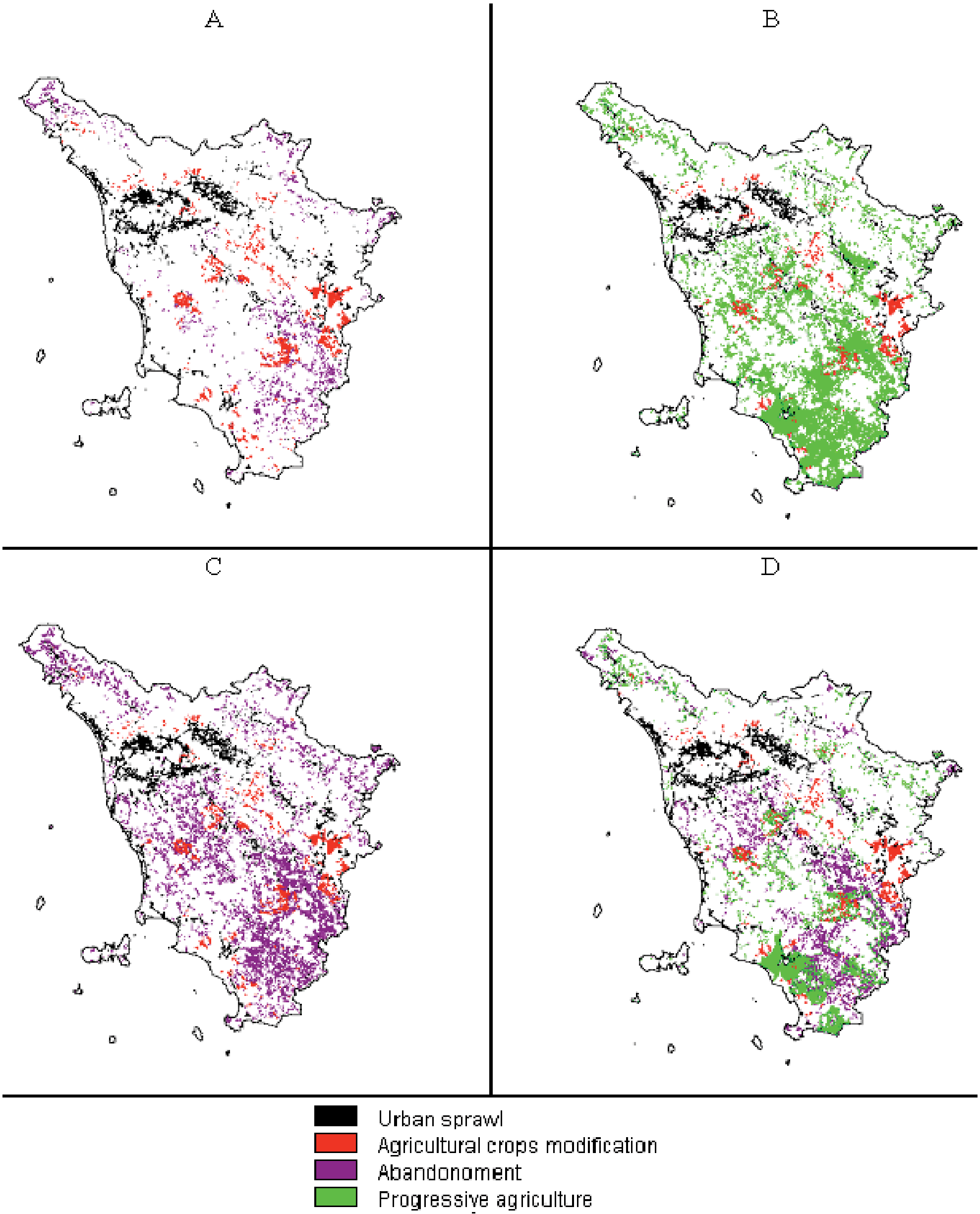
Scenario B: multifunctionality and income support

In this scenario it is possible to trace a slight decrease in urbanisation resulting from local policies aimed at concentrating urbanization in designated areas, leading to a compact urbanization pattern.

The scenario is characterised also by rural development policies aimed at raising the ecological value of the territory and driving agriculture towards high-quality production. Agroforestry measures represent almost 40% of the changes in this scenario and serve to avoid land abandonment and passive evolution of agricultural lands towards re-naturalisation. High-quality products (both organic agriculture and PDO/PGI products, which are strictly linked with the variety of local and historical production activities) represent 44% of total changes and offer the possibility to preserve agricultural biodiversity, and cultural and historic values of agriculture, especially in the South of Tuscany.

This scenario can be perceived as a hybridisation of "old" and "new" agricultural policies: the impact of environmental measures and the support of high-quality productions is very evident, but the system of payments is still not decoupled and does not guarantee an efficient evolution of agricultural activity in the areas that have no suitability for high-quality products and production systems, even though the conversion to agroforestry seems to represent a valid direction according to the simulation.

Figure 9. Scenario maps.



Scenario C: CAP suspension

Scenario C, more than the others, is characterised by major environmental pressure on the regional landscape. The suspension of income support causes widespread abandonment of arable land and heterogeneous rural areas (62% of changes), especially in the South and Centre of the region. Agricultural land is abandoned also on the Appennine mountains, causing hydrogeological risks.

The abandonment risk under this scenario's hypothesis further validates the motives of the "exceptions" to the single farm payments introduced with the Mid Term Review. The introduction of a form of support that is not linked to production levels shows the relevant possibility of the discontinuation of certain crops and the abandonment of rural land, with sowable land being among the most threatened by these measures. Because of these risks, the CAP Mid Term Review tries to ease the transition to single farm payments by allowing the Member States to adopt a partially coupled system of payments (in particular, 25% of total national payments to sowable lands can still be linked to production levels, as well as shares of special support measures for specific cultivations).

At the same time, it is possible to observe a rapid growth of urbanisation (25% of transition areas) that is concentrated in a relatively limited area of Tuscany. It embraces the Florence-Prato-Pistoia metropolitan area, and the territorial systems of Lucca and Pisa, connecting them to Florence along the Arno Valley (Pontedera, Santa Croce, Empoli and Signa). This elliptical ring of small to medium-sized cities is characterised (compared to other Tuscan territorial systems with networks of cities immersed in vast rural, hill and mountain systems, such as the provinces of Siena, Arezzo and Grosseto) by very critical environmental, settlement, landscape and social features. Indeed, urban growth occurs around some of the cities with higher artistic value, isolating them from the landscape context of the Tuscan hills.

All in all, scenario C might be the one that shows the greatest impact on both the environment and socio-cultural values.

Scenario D: multifunctionality without income support

This scenario shows an attempt at mitigating the (likely) impacts of scenario C with the environmental and rural development policies of scenario B. These policies seem to have a limited impact on the expansion of urban areas, which still represent 21% of changes in this scenario. On the contrary, agricultural policies seem to be more effective in limiting the abandonment of rural areas (from 133,500 hectares in Scenario B to 33,000 hectares in scenario D, a 75% decrease). These policies show maximum effectiveness in the Maremma area (South of Tuscnay), while abandonment is concentrated mainly in the sowable lands of the Pisa and Siena provinces (Centre and South West). The result is a regional evolution that shows rather homogeneous areas:

- the elliptical city, strongly urbanised and industrialized;
- the mountain area, characterised by agro-environmental measures;
- the South area, where the typical characteristics of rural landscape are preserved;
- the Centre area, where agriculture shows signs of changes towards abandonment or towards specialised viticulture.

5.2. Landscape Impact Assessment

The environmental impact of land use changes does not depend only on the total change but mainly on the localisation of the changes in relation to the condition of bordering pixels. Because of this, the environmental impact assessment of the four scenarios was approached using indicators that were constructed by focal analysis procedures. This approach was used largely for environmental analyses (Farina 1998, Hatten and Paradzick 2003), degradation pattern (Tanser and Palmer 1999) and urban expansion assessment (Bianchin and Bravin 2004). The following procedure was used. First, three Boolean maps were made for each scenario: urban areas, rural areas and natural areas. The maps of the four scenarios were constructed, calculating the focal mean on a 13 × 13 kernel (about 1 km), a reasonable size to show the impact of the changes on the neighbourhood landscape (Bianchin and Bravin 2004). The filter that was employed gives us the percentage of pixels that are in a certain condition inside the window. Using this elaboration, the following impact indices were calculated:

- edification index: percentage of urbanised pixels;
- rural index: percentage of agricultural cultivation pixels;
- ecological connectivity index: percentage of natural, semi-natural or agroforestry pixels.

These indices maintain a high level of cartographic detail, as shown in Fig. 10, where some of the hot-spots for the phenomena that were analysed in the Tuscan region are shown.

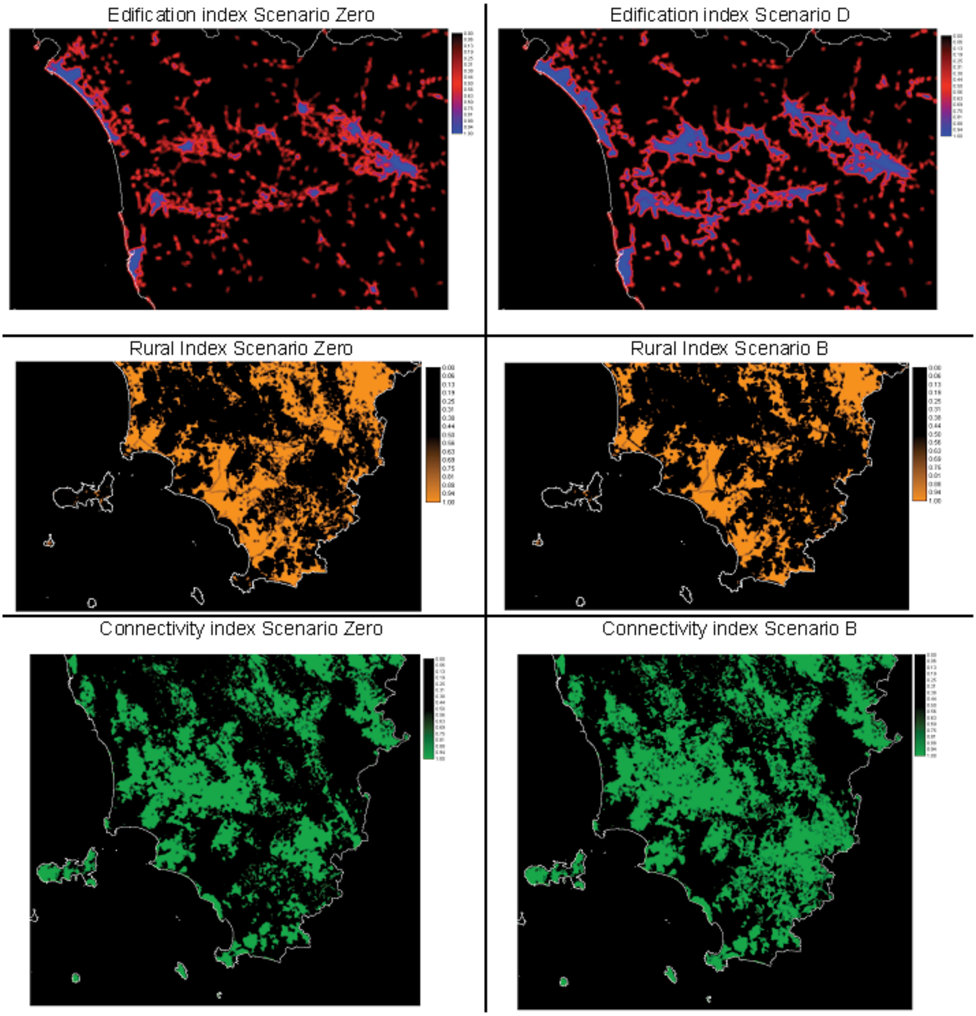
These indices allowed us to single out four criteria that are the basis for the appraisal:

1. to minimise soil impermibilisation, measured by the total number of pixels with edification index > 0.5 (Bernetti and Fagarazzi 2002);
2. to minimise the expansion of low-density urban areas in the landscape, measured by the total number of pixels with edification index 0.125-0.5 (Angel *et al.* 2007);
3. to maximise rural landscape preservation, measured by the total number of pixels with rural index > 0.75 (Ayad 2005);
4. to maximise ecological connectivity, measured by the total number of pixels with ecological connectivity index ≥0.6 (Farina, 2000).

With this approach it was possible to build an environmental impact assessment matrix for the scenarios. The procedure was calculated also for the year 2000 (scenario zero) as a reference to emphasise the improvement or the worsening of environmental quality. The matrix was evaluated with the compromise programming (CP) method.

CP is a mathematical programming technique used to identify solutions that are closest to the ideal solution, as determined by some measure of distance. The

Figure 10. Hotspot of environmental evaluation.



solutions identified to be closest to the ideal solution are called compromise solutions and constitute the compromise set. The ideal identifies the optimum solution for all the criteria, while the nadir identifies the worst option (anti-ideal). These two points, separate and distinct, together provide extreme values for the criteria in the result space. The distance from the ideal solution for each alternative is measured by the distance metric (Cochrane and Zeleny 1973). Equation (9) is the operational expression used to compute the family of distance metrics (L_j) for a set of n criteria and m alternatives.

$$L_{sc} = \left[\sum_{crit=1}^{C} \left| \frac{f^*_{crit} - f_{crit,sc}}{f^*_{crit} - f_{*crit}} \right|^p \right]^{1/p} \tag{9}$$

where:
L_{sc} is the distance metric for scenario sc
f^*_{crit} is the ideal value of the criteria
$f_{*\,crit}$ is the anti-ideal value of the criteria
$f_{crit,\,sc}$ is the value of the criteria for alternative sc
p is a parameter ($1 \leq p \leq \infty$)
$crit$ is the number of criteria $crit = 1,\ldots,$
sc is the scenarios.

The parameter p reflects the importance of the maximal deviation from the ideal point. For $p = 1$, all deviations are weighted equally; for $p = 2$, each deviation is weighted in proportion to its magnitude. The larger the deviation, the larger the weight. For the value of $p = \infty$, the min-max criterion is achieved.

Tab. 7 shows the impact matrix, the distance matrix and the results of the evaluation for parameter $p = 1$ and $p = 2$ (the results for $p = \infty$ are rarely calculated as they lead to the loss of information content, the results for $p > 2$ usually do not change the rank that is obtained for $p = 2$). The Table shows that scenarios A and B dominate over the others, at least for the criteria examined (Zeleny 1982). Scenario A is the one that seems to better preserve the traditional rural landscape, which is altered by the changes toward guided re-naturalisation of agricultural areas, while scenario B achieves better results in terms of minimising soil sealing and urban sprawl. On the contrary, it is important to notice that agro-environmental measures and the incentives for high-quality cultivation do not seem to compensate for the negative effects of the strong growth of urbanisation for scenario D.

The comparison with scenario zero shows the worsening of the soil sealing index, due to the growth of urban areas in all the scenarios, and of the rurality index, due to the decrease of traditional agricultural areas in all the scenarios. On the other hand, improvements are shown with respect to the landscape impact of urban fronts and ecological connectivity.

6. Discussion and Conclusions

The approach used here has shown the possibility of constructing land change scenarios using typical landscape planning scales of 1:25,000 and 1:100,000. The localisation of changes derives from the interaction between:

- geographical and environmental variables, available on a GIS platform;
- socio-economic characteristics, surveyed by small area census data;
- agricultural and land policies, represented by the scenario dimensions.

Table 7. Scenarios impact assessment

	Scenario	Landscape impact	Soil sealing	Rurality	Ecological connectivity
Impact matrix (hectares)	Zero	598,400	93,637	1,091,553	1,959,146
	A	572,056	182,628	997,632	2,002,316
	B	571,260	175,676	845,090	2,306,636
	C	579,075	209,028	848,172	2,259,010
	D	579,159	209,471	861,057	2,225,618
Ideal point (distance matrix)	Zero	1.00	-	-	1.00
	A	0.03	0.77	0.38	0.88
	B	-	0.71	1.00	-
	C	0.29	1.00	0.99	0.14
	D	0.29	1.00	0.06	0.77
Evaluation (distance matrix)		$p = 1$	Rank $p = 1$	$p = 2$	Rank $p = 2$
	Zero	2.00	2	1.41	3
	A	2.05	3	1.23	1
	B	1.71	1	1.23	1
	C	2.41	5	1.44	4
	D	2.12	4	1.29	2

The characteristics of the simulations that were performed allow for the use of the model's result as a bridge between urban and rural planning. Indeed, the results showed how agricultural policies are capable of being effective and driving the changes only in the absence of urban expansion dynamics. Moreover, the European Landscape Convention enjoins the preservation of both typical and degraded per-urban landscapes.

"Article 2 – Scope: Subject to the provisions contained in … this Convention applies to the entire territory of the Parties and covers natural, rural, urban and peri-urban areas. It includes land, inland water and marine areas. It concerns landscapes that might be considered outstanding as well as everyday or degraded landscapes"

(European Landscape Convention, Florence, 20 December 2000). More recently, the European Economic and Social Committee, in the "Opinion of the Section for Agriculture, Rural Development and the Environment on Agriculture in peri-urban areas has established that: "peri-urban agriculture undoubtedly faces specific constraints stemming directly from characteristics that can be easily identified and defined. Specific measures must therefore be introduced for the conservation, planning and management of peri-urban areas with agricultural activity" (NAT/204 - CESE 1324/2003). At this level, the described model can define, with a sufficient level of detail, the landscapes that will be subjected to heavier urban expansion pressures. More thorough analyses for the construction of specific scenarios for landscape and peri-urban areas planning are still needed, as the results described above showed that urban sprawl phenomena concern internationally renowned cities (Florence, Pisa, Lucca) and landscapes (Chianti, Florentine hills) in Tuscany.

The analysis has shown how agricultural policies can drive agriculture in prevalently rural areas with no viticulture. Transitions toward high-quality agriculture are, in this case, concentrated in hill areas, while agroforestry actions seem to be spreading in mountain areas. Specific local scenarios are needed in this case too, in order to better plan rural development policies.

The models have shown how the risk of abandonment is an important phenomenon that characterises the Tuscan landscape. The Tuscan case study described here confirms the results of previous studies on a larger scale and with lower resolution (MacDonald *et al.* 2000; Eetvelde and Antrop 2004; Verburg *et al.* 2006). The abandonment of agricultural lands in the Mediterranean area is a very complex phenomenon, as it involves landscape scenic beauty as well as ecological (Theobald 1997; Naveh 2001; Zavala and Burkey 1997), hydrogeological and social aspects. The impact on the landscape is connected closely to the peculiarities of Tuscany. It is generally perceived that the beauty of a landscape is a function of its heterogeneity (see Ayad 2005, Crawford 1994 and Germino *et al.* 2001). This rule seems to be too simple for the Tuscan landscape, which is a result of the interaction between environmental factors and human actions (see cultural Landscape concept like in Farina 2000b). In this sense, many of the typical Tuscan landscapes are subjected to the negative effects of abandonment. Protection of soil from erosion is a serious concern in dry Mediterranean areas where soils are thin and fragile, and where vegetal cover tends to be sparse. Abandonment may increase the likelihood of soil loss, especially when terraces are unmaintained (see Bernetti *et al.* 2003). Here, too, the results can be better examined using specific scenarios.

In conclusion, the advantages of the method described here come from the possibility of using both the ex-ante and ex-post point of view, geo-referencing and the level of detail for the results and the possibility of integrating different methodologies for the analysis.

On the other hand, there are still weaknesses: farmer individual behaviour models are not defined with sufficiently details, and the transition matrix used to describe the final status does not seem to be sufficiently flexible or efficient to describe the final demand for land use.

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