Linking processes and pattern of land use change
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Comparison of a deductive and an inductive approach to specify land suitability in a spatially explicit land use model

Abstract

In this chapter, two research approaches to specify the relation between land use types and their explanatory factors are applied to the same modelling framework. The two approaches are used to construct land suitability maps, which are used as inputs in two model applications. The first is an inductive approach that uses regression analysis. The second applies a theoretical, actor decision framework to derive relations deductively using detailed field data. Broadly speaking, this classification coincides with the distinction between empirical and theoretical models and the distinction between deriving process from pattern and pattern from process. The two modelling approaches are illustrated by a scenario analysis for a case study in a municipality in the Philippines. Goodness-of-fit of the deductive approach in predicting current land use is slightly lower compared to the inductive approach. Resulting land use projections from the modelling exercise for the two approaches differ in 15 percent of the cells, which is caused by differences in the specification of the suitability maps. The chapter discusses the assumptions underlying the two approaches as well as the implications for the applicability of the models in policy-oriented research. The deductive approach describes processes explicitly and can therefore better handle discontinuities in land use processes. This approach allows the user to evaluate a wide range of scenarios, which can also include new land use types. The inductive approach is easily reproducible by others but cannot guarantee causality. Therefore, the inductive approach is less suitable to handle discontinuities or additional land use types, but is well able to rapidly identify hotspots of land use change. It is concluded that both approaches have their advantages and drawbacks for different purposes. Generally speaking, the inductive approach is applicable in situations with relatively small land use changes, without introduction of new land use types, whereas the deductive approach is more flexible. The choice of modelling approach should therefore be based on the research and policy questions for which it is used.

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5.1 Introduction

Within LUCC (land use and land cover change) research much attention has been paid to the development of models (Briassoulis, 2000; Veldkamp and Lambin, 2001; Parker *et al.*, 2003). Land use models are used as a tool to combine different aspects of the comple land use system and therefore enable researchers to study the dynamics of this system. Furthermore, land use change models are applied to evaluate scenarios to inform policy makers (Brown *et al.*, 2004; Solecki and Oliveri, 2004)
In reviewing land use models many criteria have been used to classify models: for exam ple, whether a model is economic or non-economic, spatially explicit or not or whether the model is statistical/empirical, mathematical or rule-based (Briassoulis, 2000; Brown *et al*., 2004; Verburg *et al*., 2004d). Most of the current land use models have in common that they all try to combine human and natural processes, which implies the involvemer of various disciplines (Couclelis, 2001). In this chapter we will use the broad distinction between deductive and inductive approaches of modelling (e.g. Laney, 2004; Overma *et al*., 2006 (Chapter 3)). Broadly speaking, this classification coincides with the distinction between theoretical and empirical models and the distinction between deriving pattern from process and process from patter
Overmars *et al*. (2006) (Chapter 3) identify six types of modelling, which vary from completely deductive to completely inductive. In this study two of these types will be used to specify the relation between land use and its explanatory factors, which will be implemented in two applications of a spatially explicit land use model in the same regio The first approach can be classified as 'unstructured factors induction'. In this approacl conceptual framework is used to define the dependent variable and the independent va ables but then leave it to the procedures of statistical inference to find correlations betw these variables. Theories are used to construct hypotheses about the relation between la use and its explanatory factors, but the structure of these theories is not used or tested (e Serneels and Lambin, 2001; Nelson *et al*., 2004). The second, more deductive approach use in this chapter is called 'imposed theory'. In this approach a land use theory is specified for a real world case in terms of both structure and parameters, without any fitting to empirical data, and used to predict land use
The two approaches to quantify the relation between driving factors and land use, resul ing in a land 'suitability' estimate, will be implemented in two applications of CLUE-S, which is a dynamic land use model, to simulate scenarios of LUCC in a study area in the municipality of San Mariano in the northern part of the Philippines. The remainder of th model setting will be kept the same for the two modelling approaches to be able purely assess the effect of having different methods to specify land suitabil

The aim of this chapter is to compare the differences between the two model applicatio which have different specifications of land suitability as input. The difference in outco of two model applications as well as the different assumptions underlying the two mod specifications will be discussed. Furthermore, the chapter describes the implications for applicability of the approaches for different research and policy questio

5.2 Study area and data collection

5.2.1 Study area

The study area is situated in Cagayan Valley in the northeastern part of the island Luzon the Philippines (Figure 5.1). The study area includes 1(*barangays* (villages) in the munici-pality of San Mariano, in the province of Isabela, and its size is approximately 26,000 ha. is situated between the town of San Mariano in the west and the forested mountains of t Sierra Madre mountain range in the east. The area is inhabited by approximately 16,500 people (about 3,150 households) of various ethnic groups, among whom the Ilocano, Iba nag and Ifugao, who are migrants or descendents of migrants that came to the area from the 1900s onwards, and the Kalinga and Agta, who are the indigenous inhabitants of the area. At present, the study area shows a clear land use gradient ranging from intensive a riculture, with mainly rice and yellow corn, near San Mariano to a scatt ered patt ern of yellow corn, banana, grasses and trees to residual and primary forest in the eastern part the study area. Before immigration started the area was completely covered with tropica lowland forest. About 76 percent of the population has farming as their main source of livelihood and another 12 percent is involved in working on other people's farn

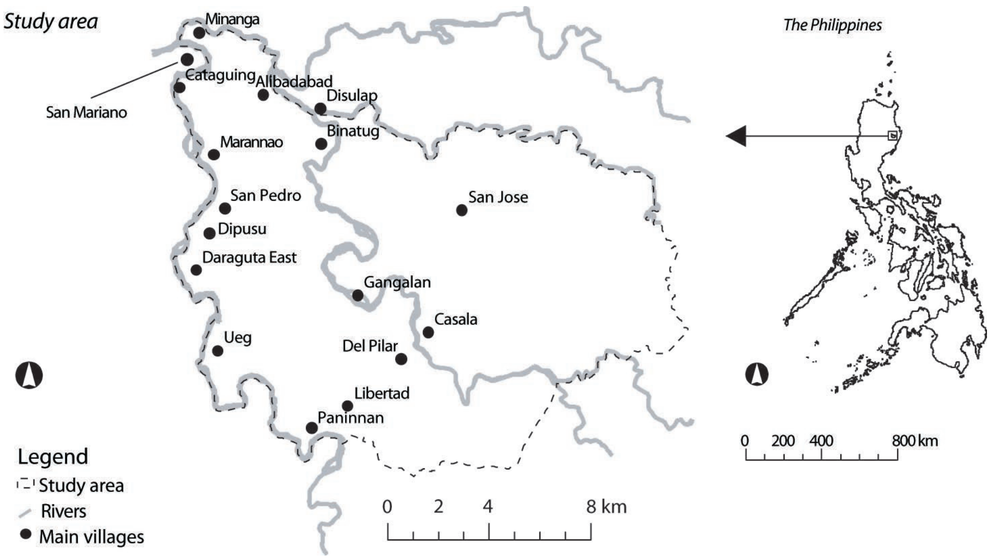

Figure 5.1: Study area

5.2.2 Data

Land use data were interpreted from two remote sensing images, a Landsat ETM+ imag (htt p://www.landsat.org) from June 2001 and an ASTER image from March 2002. First, unsupervised classifi cations of both images were made for the study area. Second, the classes of the unsupervised classifi cations were recoded into land use types according t a set of 96 fi eld observations. Finally, the land use map was constructed by combining t classifi cations of the two images. In this procedure the ASTER image was fi rst resampl from 15m resolution to the same grid as the Landsat image (30 by 30 m). Then, all land u classes of the two images were put in separate layers. In a GIS (Geographical Informatio System) these layers were combined, using overlay, where the delineation of the top lay overrule those of the layers underneath, in order to obtain the best fi t with the fi eld obs vations. This way the best elements of two images were combined and the best overall l use classifi cation was created. To improve the identifi cation of wet rice fi elds an extra image from July 2001 was used. Finally, the image was resampled (aggregated) to a 50 b 50 m grid that coincides with the other data. Resampling was performed by taking the value of the original map under the centre point of the newly created grid. Classifi catio accuracy of the land use map is 68 percent, which was calculated using an independent sample of 76 fi eld observations (Verbu *et al*. 2004a).

In creating the land use map from remote sensing images banana plantations and low-density forest types (secondary forest) were diffi cult to separate from each other, becau banana cultivation is quite extensive and oft en many trees grow in between the banana which results in a similar spectral refl ection as secondary forest. Therefore, a class that included both banana and secondary forest was manually divided based on fi eld obser tions into a part with predominantly banana and a part with predominantly secondary forest. The western half of the area was identifi ed as an area in which this class can be considered to contain almost exclusively extensive banana plantations. In the eastern pa the same class is considered to be predominantly secondary forest. The resulting land u map is depicted in Figure 5.5A

The set of explanatory variables is based on a previous analysis (Overmars *et al*., 2006 (Chapter 3)) and includes slope, ethnicity variables, accessibility variables, potential for rice and a reforestation policy. The slope map was derived from a 1:50,000 topographic map of the area (NAMRIA, unknown). This slope map was reclassifi ed into fi ve slope classes that correspond with classes in the survey held amongst farmers in the area, whi was used in the deductive approach. It was not possible to obtain a map that depicts the ethnicity of the individual landowners, because no data were available that link all land managers to their individual parcels. Instead, maps of the percentage of every tribe per village were created based on census information of the National Statistics Offi ce. The accessibility measures in this study are based on an in-depth study on accessibility in th study area (Verbur *et al*., 2004a). The time farmers have to travel from their homes to th fi elds is calculated with a cost distance algorithm. In this calculation diff erent travel sp were att ributed to diff erent types of roads and off road and these were used to calcula minimum travel time. Transportation costs are calculated by assigning the transportatio costs (to the market place in San Mariano) of the nearest village, based on the travel tim calculation, to all locations. A map with the possibilities for irrigation to cultivate wet ri was constructed from a map indicating the area within 200 m distance to a creek (excluc big rivers) and a map indicating the land that can potentially be served by a NIA (Natio Irrigation Agency) project that was established in the area. These rules were combined t map containing location with and locations without the possibility of cultivating rice. Th fi nal data source is a map delineating an area which is targeted by a policy called SIFM (Socialized Industrial Forest Management Agreement), which promotes the planting of trees (DENR-CENRO, 1998). Within this policy farmers were off ered 25 years of tenure rights on the condition that they plant a certain area with (fruit) trees (mainly mango, citrus and coconut). In the study area this policy was especially promoted by an NGO that provided free seedlings and assisted the farmers in obtaining the tenure documents (General, 1999)

Table 5.1: Descriptive statistics based on a 5 % sample of the complete dataset, n = 5002

Variable name	Description	Min.	Max.	Mean	St. dev.
Land use variables					
Wet rice	1 if wet rice, 0 otherwise	0	1	0.02	
Yellow corn	1 if yellow corn (and 10% other arable crops), 0 otherwise	0	1	0.21	
Banana	1 if banana, 0 otherwise	0	1	0.17	
Grass	1 if grass 0 otherwise	0	1	0.30	
Sec. forest	1 if secondary forest 0 otherwise	0	1	0.17	
Forest	1 if forest 0 otherwise	0	1	0.09	
Water bodies	1 if lake or river, 0 otherwise	0	1	0.02	
Explanatory variables					
Slope1	1 if slope < 2.5 degrees	0	1	0.22	
Slope2	1 if 2.5 ≤ slope < 6.5 degrees	0	1	0.25	
Slope3	1 if 6.5 ≤ slope < 12.5 degrees	0	1	0.34	
Slope4	1 if 12.5 ≤ slope < 20.5 degrees	0	1	0.16	
Slope5	1 if slope ≥ 20.5 degrees	0	1	0.04	
Dist. to small river	1 if distance to a small river < 200 m or part of NIA irrigation project	0	1	0.26	
Plot distance	Minutes walking to the plot (min.)	0	405	76.63	73.02
Transportation cost	Cost to transport a bag of corn from the house to San Mariano (pesos)	0	45	25.50	10.18
Ethnicity Ilocano	% in the barangay that is Ilocano	2.09	96.6	67.95	22.53
Ethnicity Ifugao	% in the barangay that is Ifugao	0	40.42	7.07	12.72
Ethnicity Ibanag	% in the barangay that is Ibanag	0	89.47	13.06	16.67

5.3 Methods

5.3.1 Overview

In this section the inductive and deductive approach to derive the relation between land use and its explanatory factors *i.e.* 'suitability' maps) are presented. The inductive mode using logistic regression analysis, is rather straightforward. The deductive approach use an actor decision framework. This approach is less known than the inductive approach and is therefore described in more detail. Both approaches make use of the dataset described in Table 5.1. So, diff erences between the results of the two approaches cannot ar from diff erences in the specifi cation of variables. However, as will be explained, the tw approaches diff er in their model specifi cation, for example, they use a diff erent selectic of variables from this dataset and diff erent model parameters. Moreover, the deductive approach additionally includes variables that are constant over the area (e.g. prices and investments levels). This will result in diff erent outcomes of the two approach
The resulting suitability maps of the two approaches are input to two diff erent applicat

of CLUE-S. CLUE-S is a spatially explicit and dynamic land use model, which is describ below. The suitability maps produced with either the inductive or the deductive approa provides only one of the mechanisms that are responsible for land use distribution in th CLUE-S model. The other mechanisms and their inputs are modelled the same in both model applications

Finally, we describe two scenarios that are used to illustrate the two modelling applica- tions. One scenario is used for both model applications to compare diff erences. A secon scenario introduces a new land use type and is only applied in the model with the dedu tive approach

5.3.2 Approaches to determine the relation between land use and its explanatory factors

Inductive approach

In the inductive approach the suitability of a location for a land use type is determined i an empirical way by using logistic regression analysis. This regression model describes the relation between the occurrence of a land use type and the set of explanatory variabl (Table 5.1) that are considered to infl uence land use allocation. The current land use is assumed to refl ect the infl uence that these explanatory variables have exerted on the la use.

The dependent variables in the analysis are binary maps where the land use type under study has a value 1 and all other land use types have value 0. The variables that were inserted in the regression models were selected with a forward stepwise regression pro- cedure (with probability levels of 0.01 for entry in the model and 0.02 for removal from the model). Originally, the data stems from fewer observations than a representation as grid would suggest and all cells would be considered to be observations. Therefore, a fi percent sample was drawn from the original dataset of 99,863 cells to reduce spatial aut correlation in the analysis. Sampling from a grid is a commonly used method in analysi land use patt erns and will minimise spatial autocorrelation to a level that it will not aff the results (Serneels and Lambin, 2001; Stoll *et al.*, 2003). Based on the logistic regression analysis the probability of fi nding the land use type at each location can be determined. These probabilities are assumed to indicate the relative suitability of that locatio

Deductive approach

Action-in-Context (AiC) (De Groot, 1992) is a methodology for problem-oriented researc that puts activities of actors, for example land use, into context to gain insight in the cau of the activities. Based on Vayda (1983), the research sequence of the AiC methodology i to start with the actions under study, to identify the decision-making social entities dire behind these actions, and then to study the range of options available to the actors and t motivations att ached to these (Verbur *et al.*, 2003). One of the elements of the AiC meth- odology is the 'deeper analysis', which ties the options and motivations of the primary actor to underlying cultural and structural factors. The structural framework of the deep analysis will be used as an actor-model to study the decision-making process of farmers who are the primary land managers in the study are

The structural framework of the deeper analysis is depicted in Figure 5.2 (De Groot, 199 where the arrows show the direction of the causal relations. The fi rst layer in Figure 5.2

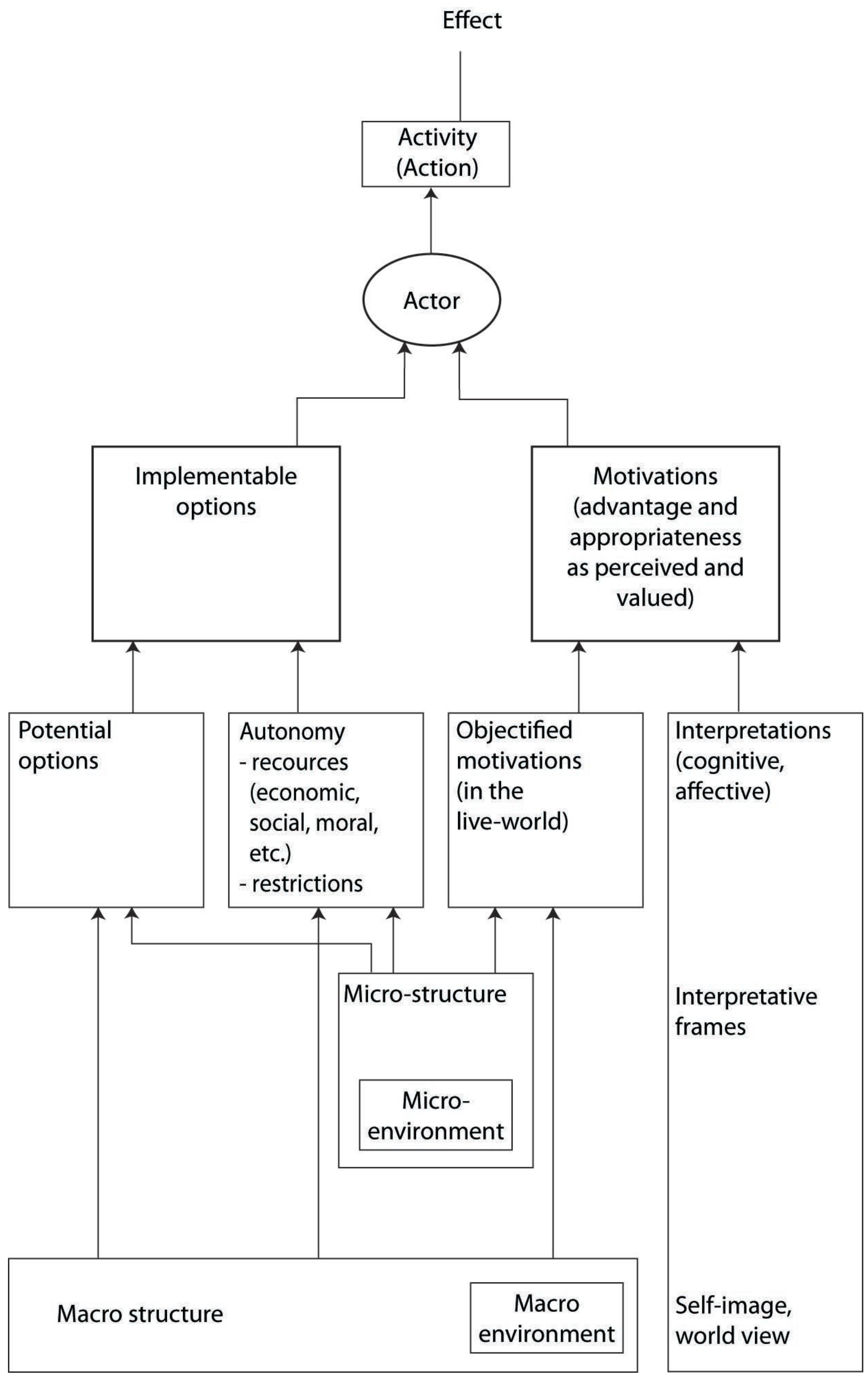

Figure 5.2: Structure of the deeper analysis of the Action-in-Context methodology (De Groot, 1992)

consists of three elements: effect, action and actor. In the case of land use, effects can be
degradation, biodiversity loss and greenhouse gas emissions, for example. Though, in th
study the land use actions rather than the effects are the subject of study. The actors are
social entities that exercise a significant decision-making capacity on the activity. In this
study the actors are farmers. An example of the relations in the first layer is a farmer (ac
who grows corn (activity), leading to soil degradation (effec
The second layer consists of 'implementable options' and 'motivations as interpreted'.
Implementable options are built up from 'potential options' and 'autonomy' (layer 3).
Potential options are all options the actor is aware of. Though, not all of these options ca
be implemented. The difference between the implementable options in the second layer
and the potential options in the third layer is the difference between what the actor real
can do as opposed to what the actor might do if he had the possibility. This difference is
determined by the so-called autonomy of the actor. The autonomy consists of resources
and restrictions, which together determine which options an actor can implement. Re-
sources contribute to the actor's capacity to implement actions they consider. The nature
of these resources can be economic, social, cognitive, environmental, moral, psychologic
and physical. For example, for a farmer to grow corn he needs access to land, money to
buy inputs and the knowledge how to cultivate corn. Restrictions are autonomy reducin
factors, like prohibitions, prescriptions and standards related to environmental licences,
but also include physical restrictions
Motivations are the aspects of the options under consideration by the actor that are norm
tively relevant to the actor *i.e.* that give value to the different options). In layer two the m
tivational factors are specified in terms of 'advantage and appropriateness' as interprete
by the actor. These interpreted motivations are determined by 'objectified motivations'
'interpretations' (layer 3). The objectified motivations are easily quantifiable units, such
as economic costs and benefits or caloric value of produced foods (Verburg *et al*., 2003).
Interpretation is shaped by the cultural and psychological opinions and ways of looking
that give weight, coherence, shape and colour to the objectified motivations. Together th
form the motivations as interpreted by the acto
In the fourth layer the factors of the third level are seen as being determined by 'micro-
structure', 'macrostructure' and 'interpretative frames, self image, world views', which
is the cultural aspect of the actor's context. A more elaborate description of the deeper
analysis can be found in De Groot (1992) and Overmar *et al.* (2006) (Chapter 3)
The options and motivations of the deeper analysis are used to construct the relations be
tween land use and the explanatory factors in a theoretical-deductive manner as oppose
to the inductive method described above. Normally, the AiC approach is applied to case
in which actors or households are the objects of study (e.g. Overmar *et al.*, 2006 (Chapter
3)). In the CLUE-S model locations, regular grid cells of 50 by 50 m, are the unit of analy
Therefore, the options and motivations of land managers have to be converted into suit-
ability maps. This conversion is not always straightforward (Overmars and Verburg, 20
(Chapter 2)). The field characteristics from the deeper analysis can be easily represented
in maps, because field characteristics are directly linked with locations. The influence o
household characteristics on land use, as determined in the deeper analysis, is more dif-
ficult to incorporate in the suitability maps, because household data are not available in
maps. Instead, the household variables are represented as aggregates at the village level
This aggregation may lead to aggregation problems, but the logistic regression analysis
of the deductive approach revealed that the aggregated effects of the household variabl

(ethnicity) are also present. The interpretation of those variables should be made on vill level, because the relations at village level can be diff erent from the relations at househo level.

As far as the policies and restrictions are spatial these can also be directly represented in maps. Some spatial policies restrict all land use change in a certain area, like, for exampl the protection of a nature reserve which is implemented very strictly. Other land use po cies restrict a single land use conversion, like the prohibition of the construction of hous in designated agricultural areas or permanent agriculture in the buff er zone of a nature reserve.

An important diff erence between the regression approach and the deeper analysis is th way potential options are modelled. In the deeper analysis spatial policies and restrictions (or lack of resources) reduce the autonomy of the land manager and therefore the number of options a farmer can implement. This approach really excludes land use type on certain locations, whereas in the regression analysis including variables can only lea to a reduced probability and not to a real exclusion of a land use type at a location due t the way the regression model is specifi e

5.3.3 The CLUE-S modelling framework

In this section the CLUE-S model is described and for those aspects that are the same in both modelling approaches a specifi cation is provided. The diff erence between the two model applications that will be presented is the way the suitability maps are compute The modelling framework that is used is the most recent version of the CLUE-S model (Verburg *et al*., 2002; Verburg and Veldkamp, 2004; Verburg *et al*., 2004c). This modelling framework is used to integrate diff erent mechanisms of the land use system into a spatially explicit land use model that is capable of the dynamic simulation of competition a interactions that occur in land use systems. Incorporation of these mechanisms result in model output that shows path dependency and non-linear behaviour, which characteris the land use system in real-world situations. Path dependency implies that model result of earlier modelling steps have their infl uence on later modelling steps. Path dependen is dependent on the specifi cation of the incorporated mechanisms, for example land use history and conversion rules, and initial conditions (Brown *et al*., 2005). A general way to look at models, mentioned by Couclelis (2001), is that they are frameworks for organising knowledge. This description fi ts very well the CLUE-S modelling framework, whic integrates diff erent aspects of the land use change proce

The CLUE-S model consists of an allocation module and a series of inputs. The allocation module is a computer program that iteratively computes land use allocation for a number of modelling steps (a detailed description of the allocation module is provided by Verburg *et al*. (2002)). The allocation module can incorporate various mechanisms tha are considered to determine the distribution of land use changes in a landscape. These mechanisms are parameterised by the inputs of the model. The quantity of land use cha is also imposed to the model as an input. These land use requirements impose the quant of land use change per modelling step for every land use type in the whole study area. T future 'land claim' can be a fi ctitious land use scenario based on story lines, as will be u in this study, or an external modelling procedure like macro-economic modelling. Then, the allocation module allocates the aggregated land claim year by year to the cells based on the various mechanisms in an iterative way. So, the strength of the CLUE-S model is

allocate land use changes rather that modelling the quantity of chang
The mechanisms responsible for the land use allocations can be divided in location characteristics and conversion characteristics. The fi rst locational characteristic is the 'su ability', which is based on the relation between land use and a broad set of biophysical and socio-economic factors. Suitability has an important infl uence on the allocation of la use change in the model. The basic assumption behind this mechanism is that a location changes into a certain land use in those locations where the 'suitability' is high for that la use type. Suitabilities are represented as a map with values between 0 (low suitability) a 1 (high suitability). This is where the deductive or the inductive approach to derive the land use suitability maps is insertec

The second location characteristic allows for the incorporation of spatial policies. The suitability map can be altered at locations that a policy applies to. The suitability can be set to zero at locations where a land use type is not allowed to change, for example in a conservation area, or the suitability value can be adjusted by a certain value in areas tha are under a policy that, for example, awards subsidies for a certain land use in that area. This mechanism is not used in the applications in this stud

The third location characteristic is the neighbourhood eff ect (Verb *et al.*, 2004c). Althougl several theories are available addressing the interaction between neighbouring land use types, for example trends in explanatory variables or spatial processes like imitation, thi interaction was not studied extensively in this research. Neighbourhood eff ects can be included between land use types as well as within a land use type. Because the cell size the application is smaller than the average parcel size, a small neighbourhood eff ect wa implemented in the model for all land use types with themselves, simulating the cluster of land use into fi elds and parcels. The value of the neighbourhood eff ect was based on eight closest neighbours of each cell. In the calculation of the overall suitability to be use in the model the neighbourhood function determines 20 percent and the suitability map of the inductive and deductive approach determine the other 80 percer

The conversion mechanisms that can be incorporated in the model are the so-called conversion elasticities and land use type specifi c transition sequences. Conversion elasticiti can be explained as the resistance of a land use type to change location. For example, tre plantation cannot easily move to another location because the investments made to estal lish the tree plantation are lost when the plantation moved to another location to make room for another land use type. The conversion sett ings can be used to create stability in the model by assigning a large infl uence to the land use history (Verburg *et al.*, 2002). The conversion elasticities are implemented in the model as an additional suitability for those locations that are currently under that specifi c land use. The user should decide o this factor based on expert knowledge or observed behaviour in the recent past or use the factor to calibrate the model. The conversion elasticities that are incorporated in this study are estimated by the authors based on fi eld knowledge and can be motivated as follows. Grassland is easily converted and was given a low conversion elasticity. Corn h somewhat higher elasticity value since it is relatively easy to establish a corn fi eld. The requirement for corn is a cleared fi eld. For banana higher investments have to be made it takes time to before the fruits can be harvested, therefore this land use types received higher elasticity compared to grass and corn. For rice a considerable eff ort has to be ma to construct a rice paddy. Therefore, rice received a high elasticity. Secondary forest was given an intermediate value and forest a high valu

The transition sequence is a set of rules that determine the possible land use conversions

Not all land use changes are possible and many land use conversions follow a certain sequence. Sometimes these conversions include a temporal constraint. The conversion mechanisms determine to a large extent the temporal dynamics of the simulations, becau they include land use history. In the model applications most land use conversions are allowed except for changes into secondary forest and forest. The only pathway allowed changes into secondary forest is through grass or banana. The idea behind this rule is th field must be not used for five years, and thus be grassy, to become secondary (regrow forest. Banana fields in the area are cultivated quite extensively and often trees are pres It is considered that if a banana plantation is not maintained for three years this banana plantation can become secondary forest. From secondary forest it takes another five yea grow into mature forest, which is the only pathway to mature forest. The time necessary grow from one land use into another is estimated and might be subject for further resear Incorporating the effect as such does incorporate path dependency in the model, althou it might be not the exact number of years. Banana is allowed to remain for a maximum c twenty years. After these twenty years the banana plantation has to change for at least c year. This rule is based on the lifespan of a banana plantation, which is about twenty ye in the area. After these years the banana plant is not producing anymore and is replaced with an annual crop for a short period after which bananas can be replante
The various mechanisms are combined in the allocation module. The allocation of all lar use types in the case study occurs at the same time in an iterative procedure. Altogether this results in the dynamic simulation of land use competitio

5.3.4 Scenarios

Two scenarios were developed to test the models. The first scenario provides a general indication of what might happen in the research area. The principles are based on the comprehensive development plan of the municipality of San Mariano (Municipality of S Mariano and Housing and Land Use Regulatory Board, 2000). The plans and prospec- tive indicated in this document are translated into general linear trends. The quantities c change are assessments rather than detailed calculations, but will suffice for the objecti of this chapter. The second scenario introduces a new land use typ
As indicated in the planning document of the municipality, the total amount of agricultu lands will not increase substantially for two reasons. First, slope prevents agriculture to expand much further, because productivity of the steeper areas is low. Secondly, there is necessity for more environmentally-friendly activities in these areas to prevent soil erosi and flooding and to protect natural values of the area. Forested areas will be protected and grasslands with potential for forest production will be rehabilitated and protected. To improve food security and self-sufficiency the production of rice will be promoted. Furthermore, the municipality aims at an increase in productivity per hectare to meet th necessary production and idle lands (mainly unused grasslands) should be taken into production (Municipality of San Mariano and Housing and Land Use Regulatory Board 2000). The improvement of accessibility, which is also an important municipal goal, is no taken into account in this study
The scenario sketch above is translated to a quantitative yearly land claim (Figure 5.3 lef The land claim is the total area per land use type for every modelling step and serves as input to the CLUE-S model, which is specifically developed to allocate this land claim. T translation into real figures is fabricated by the authors based on the ideas of the munic

pality assuming that the changes are predominantly linear. The scenarios are a projectio of changes that might happen rather than strong predictions with a prospective valu In Figure 5.3 (left) the rice area expands by fi ve percent of the 2001 rice area per year to bett er meet self-suffi ciency in rice, which is the main staple crop of the population. The corn area increases by one percent of the 2001 area per year (allowing some agricultural intensifi cation) and banana area reduces by one percent compared to the 2001 area per year. The latt er is to represent improved production of the banana area as well as a redu interest in this crop due to diseases. Forest area remains the same to visualise the intend conservation eff ort. Secondary forest will grow by two percent. All increases of land use types are at the expense of the grass area. This scenario is used in the model application using the inductive approach as well as in the application with the deductive approac In the second scenario a new development was included (Figure 5.3 right). In a certain policy area (SIFMA) an NGO stimulated the cultivation of (fruit) trees by providing seed lings and assisting farmers to acquire a 25-year tenureship for the parcels involved. The possibility to change to fruit trees was restricted to the SIFMA area, which was identifi e as an area that needed reforestation. Using the deeper analysis framework an analysis w made for a this new land use type, which was not yet present in the original land use ma So, this scenario could only be modelled using the deductive (AiC) approach because in the inductive approach it is not possible to make inferences for land use types that are n yet present. The information of this analysis was also converted into a suitability map. With this information fruit tree plantations were introduced in the scenario for the dedu tive modelling approach. The scenario starts with a newly established area of 150 ha wit a 5 ha increase in the following years. The extra area for fruit trees was introduced at the expense of the grass area

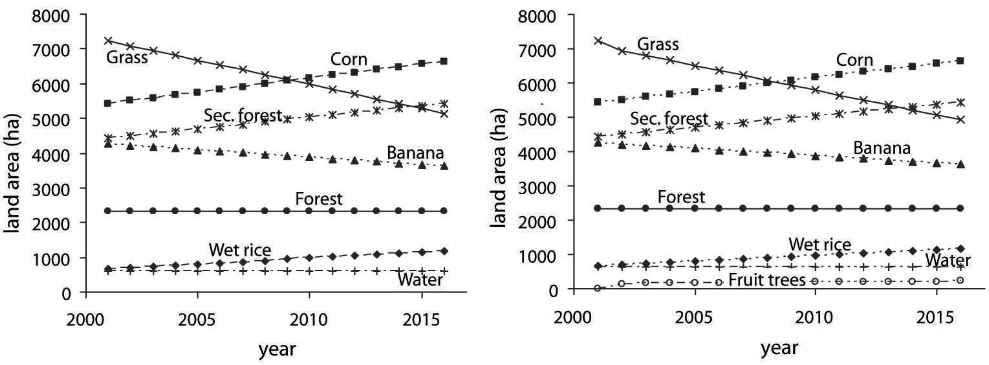

Figure 5.3: Scenario-based land claim (left) and scenario-based land claim including fruit tree plantations (right)

5.4 Results

5.4.1 Results of the inductive CLUE-S application

The results of the regression analysis that was used to determine the relation between la use and its explanatory factors are presented in Table 5.2. For rice and corn all variables were entered in the stepwise regression procedure. For the land use types banana, secondary forest and forest the ethnicity variables were excluded. Ethnicity was assumed t have no relation with these land use types. Table 5.2 shows which variables were actual included by the stepwise procedure together with their significance leve

Table 5.2: Regression coefficients of the resulting logistic regression mode

Variables	Rice	Corn	Banana	Sec. forest	Forest
Constant	-3.856***	-0.599**	-0.838***	-2.607***	-8.142***
Slope1	0.515*	1.137***	-0.655***	-0.756***	
Slope2		0.750***			
Slope3		0.399**		0.230**	0.725***
Slope4	-1.077*				1.396***
Slope5					1.551***
Creek	1.010***	-0.217*		0.313***	
Plot distance	-0.009***	-0.016***	-0.005***	0.002***	0.021***
Transportation cost		-0.026***	-0.012**	0.031***	0.084***
Ethnicity Ilocano					
Ethnicity Ifugao	0.020**				
Ethnicity Ibanag		0.011***			
ROC	0.73	0.77	0.65	0.68	0.96

** p<0.05, ** p<0.01, *** p<0.001*

The ROC (Relative Operating Characteristic) (Swets, 1988) was used to indicate the gooc ness-of-fit of the regression models. The ROC summarises the performance of a logistic regression model over a range of cut-off values. The value of the ROC is defined as the area under the curve linking the relation between the proportion of true positives versus the proportion of false positives for an infinite number of cut-off values. The ROC stati varies between 0.5 (completely random) and 1 (perfect discrimination) (see for more det Pontius and Schneider, 2001). Rice and corn have a good model fit, banana and seconda forest had a relatively poor fit and forest had a very good f

For grass and water no regression analyses were made. Grass is a left over land use type that is not used and is not cultivated intentionally. It just grows on locations that are not occupied with one of the other land use types and is therefore treated as a 'rest' category without any specific suitability. Water is considered to be constant over the modelling period and is therefore excluded from the modelling exercise. Examples of suitability m for banana and secondary forest, which are constructed with the relation found in the regression analysis, are shown in Figure 5.4A and 5.4(

The resulting land use map of the inductive modelling approach after a 15 years model period is shown in Figure 5.5B. Under the scenario and modelling assumptions applied this model the following major trends can be identified. First, the banana area decreases the area marked with 1 and is relocated in area 2. The abandoned areas in area 1 are occ with grass. In general, existing corn areas (like in the area near 3) expand throughout th area near places where corn was already present. Rice expands in the area near 4 and ju below area 2. Secondary forest increases mostly near 5. Forest is stable in this scenari

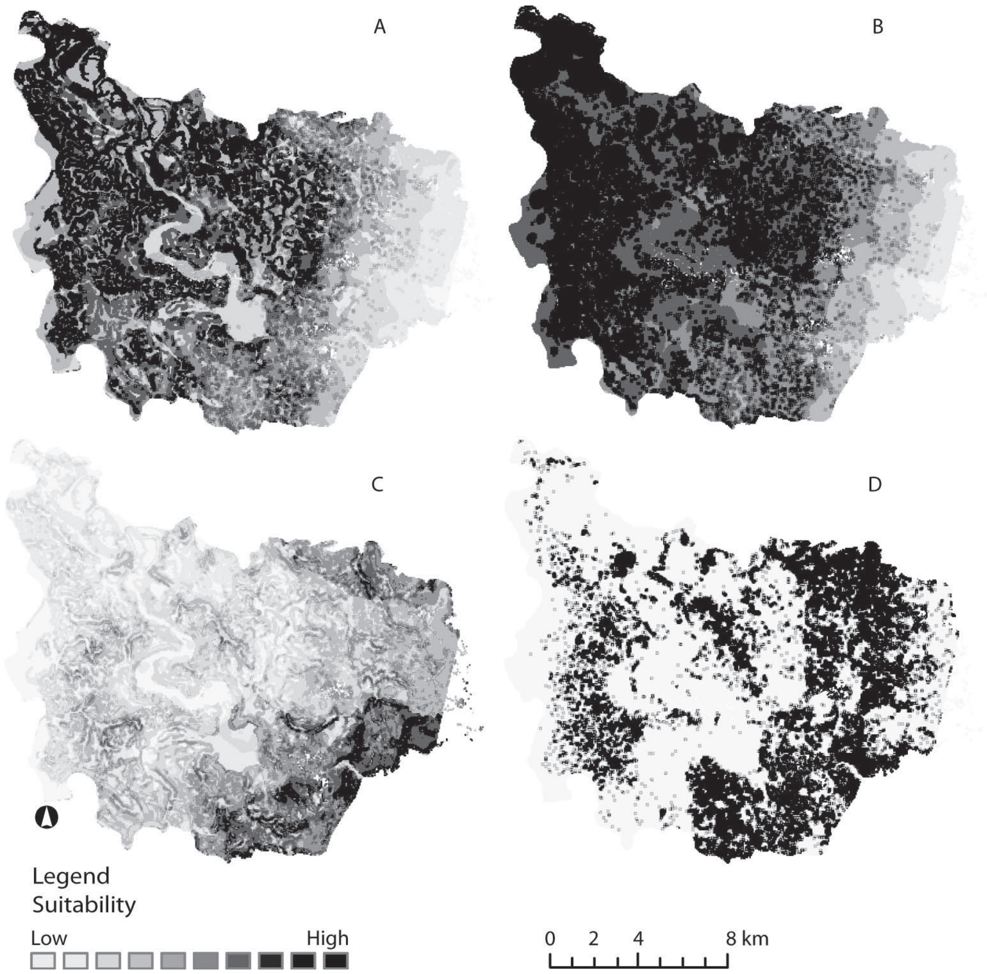

Figure 5.4: Suitability map for banana for the inductive case (A) and the deductive case (B) and suitability map for secondary forest for the inductive case (C) and the deductive case (D). The neighbourhood effect is added to these suitability maps (note that the neighbourhood effect is recalculated every time step and changes with changes in the land use). The scaling of the legends was stretched between the highest and lowest value.

5.4.2 Results of the deductive CLUE-S application

The first element of the actor decision model that is described are the motivations to cul a land use type, which are calculated according to Overmar *et al*. (2006) (Chapter 3). The relations between the land use and the explanatory factors are formulated in Equations to 5.7. For every land use type this calculation is different. The parameters for this mode were calculated using with field observations where possible and otherwise they were based expert knowledge and interviews with farmers. Not all parameters are provided i this chapter, but can be accessed from (Overmar *et al*., 2006 (Chapter 3))

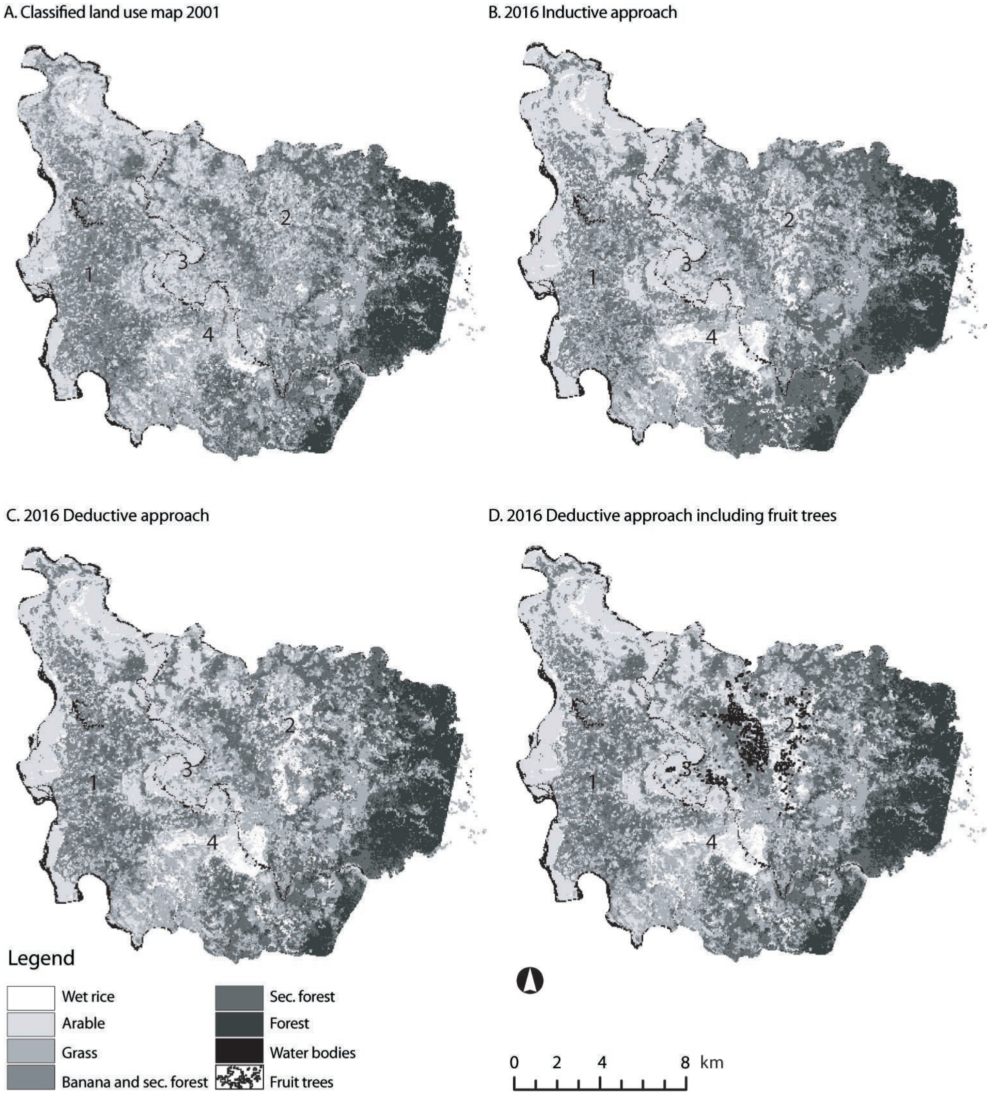

Figure 5.5: Classifi ed land use map 2001 (A), simulated land use map in the year 2016 of the inductiv modelling approach (B), the deductive modelling approach (C), and the deductive approach including fruit trees (D)

The maximum benefi t is diff erent per land use type. The slope factor applies only to co and refl ects the losses in yield due to slope. The risk is calculated from the average year loss due to typhoons, droughts, pests and diseases as reported by farmers. The costs to transport the harvested product are a combination of cost made by travelling from the fi to the residence of the farmer and transportation costs to the market in San Mariano (the latt er is not included for wet rice). Preferences for a specifi c land use type depend on th ethnicity of the household. Since the household information is not available this preferen is calculated for the village as a whole. The ethnicity specifi c preferences are multiplied the percentages of the population that belong to an ethnicity and summed for all ethnici ties. The preference for corn is considered to be higher than average for ethnicity Ibanag and low for ethnicity Ifugao. For rice the preference is high for Ilocano and Ifugao and lo for Ibanag (compared to the group of other ethnicities

*Motivations = objectifi ed motivations * preferences* (5.1)
Objectifi ed motivations (net benefi t) = (max_benefi t - tr_costs) slope_fact * (1-risk)* (5.2)
Max_benefi t = f(CROP) (5.3)
Slope_fact = f(SLOPE, CROP) (5.4)
Risk = f(CROP) (5.5)
Tr_costs = f(TR_COST, PLOT_DISTANCE, CROP) (5.6)
Preferences = f(ETHNICITY, CROP) (5.7)

The implementable options are also based on Overmars *et al*. (2006) (Chapter 3). The implementable options for rice were determined by slope, which should be fl at or fl at t moderate, and the possibilities for irrigation, close to a creek or an irrigation facility. For corn and banana no restrictions were formulated in this analysi
The options and motivations together form the suitability maps. The deeper analysis wa used to calculate suitability for rice, corn and banana. The factors that are incorporated p land use type are indicated in Table 5.3 as well as the performance of the model, which i indicated with the ROC. These ROC values were added to compare the results with the inductive approach, although the aim of the deductive approach is not to get the best fi t possible, but a good representation of the processes. This subject will be further explaine in the discussion for the case of banana. The remaining land use types were modelled as having an equal suitability for all locations. For grass we made the same assumption as i the inductive approach. In contrast with the case for grass, the other two land use types without suitability analysis actually do have a use. Forest is used for (illegal) logging an for this purpose accessibility plays an important role. Secondary forest can be also used as timber or fi rewood and therefore accessibility may also play a role. Part of these proc esses is covered by the neighbourhood functions that were incorporated. The argument not include suitabilities for forest and secondary forest in these model applications is tha under the scenario forest is stable and secondary forest is increasing. The suitability for increasing (regrowing) forest and secondary forest is not related to factors that determin suitability for logging and can actually be constant for all location
The resulting land use map of the model application with the deductive approach aft er fi ft een years modelling period is shown in Figure 5.5C. In this application the following major trends can be identifi ed. First, the banana area decreases in the area marked with and is relocated in area 2. The abandoned areas are occupied with grass and secondary forest. Like in the inductive approach existing corn areas expand. Rice expands in the ar near 4 as well as below area 2. Secondary forest increases evenly in the study area and th forest area is stable

In the second scenario applied to the deductive modelling approach fruit tree plantation are introduced. The suitability for this land use type (Figure 5.6) is similar to that of bana although the general profi tability of the fruit tree plantations is higher than the cultivati of banana. The most important diff erence with the suitability of banana is that the fruit trees are restricted to an area where the SIFMA policy applies to because in the other are

Table 5.3: Factors included in the deductive approach indicating if the factors are incorporated in the options or the motivations of the land managers

Variables	Rice	Corn	Banana	Sec. forest	Forest	Fruit trees
Slope1	options	motivations	-	-	-	-
Slope2	options	motivations	-	-	-	-
Slope3	-	motivations	-	-	-	-
Slope4	-	motivations	-	-	-	-
Slope5	-	motivations	-	-	-	-
Creek	options	-	-	-	-	-
Plot distance	motivations	motivations	motivations	-	-	motivations
Transportation cost	-	motivations	motivations	-	-	motivations
Ethnicity Ilocano	motivations	-	-	-	-	-
Ethnicity Ifugao	motivations	motivations	-	-	-	-
Ethnicity Ibanag	motivations	motivations	-	-	-	-
SIFMA	-	-	-	-	-	options
ROC	0.66	0.74	0.54			

initial investments are considered to be too higl
The land use changes are similar to those in the deductive approach (without introduction of fruit trees). The additional area for fruit trees caused other land use types (mainl banana) to move to other areas

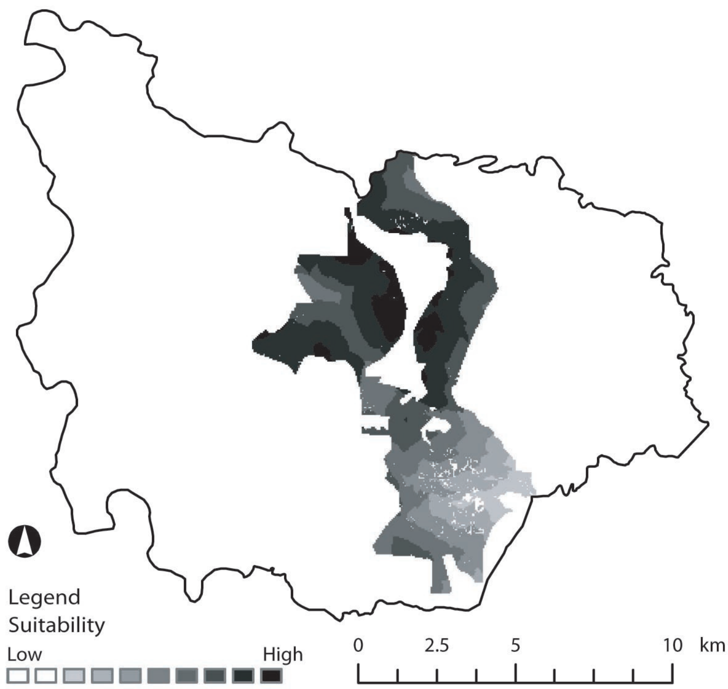

Figure 5.6: Final suitability maps for fruit trees including the restrictions

5.4.3 Comparison of the two modelling approaches

If the maps of the application using the inductive and the application using the deductiv approach (Figure 5.5B and 5.5C, respectively) are compared cell by cell the maps have 8 percent in common. In total the land use changed in 25 percent of the locations aft er 15 years. From these changes 54 percent were exactly the same changes in both modelling approaches. If the comparison is made within larger windows (Costanza, 1989), allowin for diff erences in location within the window, the similarity increases (Figure 5.
A general observation from these scenario studies is that if the grassy areas are used bot the agricultural as well as the forested areas can be improved. Agriculture is the main source of livelihood in the area and the forest can sustain the ecological function of the area. Grassland on the contrary does not contribute to production and neither has much ecological value

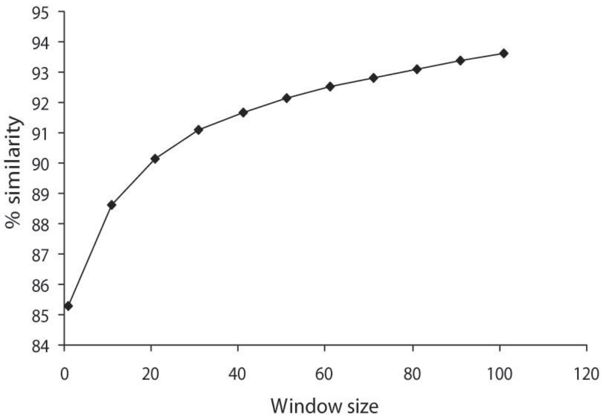

Figure 5.7: Similarity between the inductive and deductive modelling approaches with varying windo size based on their 2016 maps

5.5 Discussion and conclusions

At fi rst instance the fi nal results of the inductive and deductive modelling approaches look quite similar (Figure 5.5B and 5.5C). If only the changes are considered 54 percent of the changes are at diff erent locations. These diff erences between the maps of the twc applications are caused by diff erences in the suitability maps, which were constructed i diff erent ways. Aft er all, the other inputs and model sett i*i.e.* the neighbourhood eff ect and the conversion mechanisms) are completely identical, so these cannot cause the dif- ferences. The deductive and inductive approach to create suitability maps for a land use type can vary because of diff erent variables, diff erent relations between the variables a diff erent parameters. Some suitability maps show only local diff erences. These diff ere in suitability maps translate into diff erences in land use allocation at small distances, w disappear when the similarity is compared with bigger windows. A good example of lo- cal diff erences is the suitability of banana. In the inductive case (Figure 5.4A) slope was included while in the deductive approach (Figure 5.4B) slope was not included. As can l seen the general pattern, caused by plot distance and transportation cost (and having th same sign), is similar, but the slope introduces differences at small distances. The suitab ity maps of secondary forest show more differences. The inductive approach (Figure 5.4 detected correlation with a series of factors while in the deductive approach (Figure 5.4D no factors were included and therefore the suitability map shows only the neighbourhoo effect. These differences in suitability are reflected in the differences in the resulting la use maps even if larger windows are used in the evaluation procedur

So, the inductive and deductive approach to specify the suitability map do not always lead to the same results, because the inductive approach is based on correlation while th deductive approach is based on processes that were observed by the authors and/or described by the respondents. In other studies suitability from both approaches may be mo different leading to even more differences in the suitability maps of the two approach

Even more important is that the research paradigms of the two approaches are differen which has its implications for the interpretation and the use of the modelling approache The structural difference between the two approaches used in this study is that the deductive approach attempts to describe causality while the inductive approach to land use analysis reveals associations rather than causal relations (Serneels and Lambin, 2001 McConnell, 2002; Verburg *et al.*, 2003; Verburg *et al.*, 2004d).

In the inductive approach the current land use pattern is assumed to reflect the process of land use in the past. The result of these processes, the land use pattern, is described v the regression model using correlations between the land use and its explanatory variab The processes themselves are not described and, therefore, changes in the processes and their effect on the suitability of a location for a land use type cannot be incorporated in t modelling of future scenarios. So, using the inductive approach, the assumption that has to be made for the modelling exercise is that the processes that determine land use do no change. This approach is described by a study by Kok and Winograd (2002) where mode ling of scenarios with and without the impacts of Hurricane Mitch (Honduras) results in the same land use map after ten years under the assumption that the relations between land use and its drivers was re-established after a few years. It may be true that relation not change at short time scales, but at larger times scales different factors may become i portant and sudden events, like a change in political system may cause dramatic change in behaviour. In the models presented, however, the behavioural rules are assumed to b constant. Besides this, no new land use types can be introduced, since the relation of this new land use type with the explanatory factors cannot be determined statistically. Even the regression analysis was able to describe processes the assumption has to be made th the land use system is in equilibrium with the explanatory factors. Analysing a system t is not in equilibrium may lead to possible error in the description of the proces

The deductive AiC approach, on the other hand, describes the processes explicitly. Ther fore, changes in the processes that determine land use can be incorporated in the constru tion of the suitability maps, which enables the introduction of discontinuities and new land use types in the scenarios that are modelled. All these issues have their consequenc on the type of scenarios that can be simulated with the modelling approach. A case with discontinuity was demonstrated to some extent by Kok and Veldkamp (2000), who used a rule-based suitability map for a new land use type to enable the incorporation of this land use type, like was done in this chapter with a sound theoretical framework. The oth suitability maps in the study by Kok and Veldkamp stem from regression analys

A more technical difference between the two approaches is that with an inductive appr the regression analysis determines the relation between the current pattern of the land use types and its explanatory factors, whereas the AiC approach determines the potenti suitability of the land use types. In the regression analysis the occurrence of a land use type, which serves as the dependent variable in the regression analysis, is not independ of the other land use types. This dependency has its consequences for the applicability of the modelling approach. To illustrate this consider the example of the bananas in this study. In general, bananas are located on 'second best' locations, because the best locatic are cultivated with corn, which is (potentially) more profitable. For example, in this stu bananas are correlated with high slopes, which is due to the fact that on the flatter part corn is preferred, not because bananas grow better on steep slopes. In the inductive approach the calculated suitability for banana is high at these second best locations. If a la change in banana area would occur, for example when suddenly all corn would disapp and the banana area would expand fast (large changes may happen for example throug large price changes or diseases), these new banana areas would first be allocated on are with a high banana probability, which in fact are the second best locations. In reality the new banana would first appear where the suitability for banana is optimal. The deducti approach would allocate these where the potential suitability for banana is high. Genera speaking, the inductive approach to specify the suitability map in CLUE-S is applicable situations with relatively small land use changes, without introduction of new land use types, whereas the deductive approach to specifying the suitability map in CLUE-S approach is more flexible in this respec

The advantage of the empirical approach is that the procedure of the regression analysis is straightforward and easy to reproduce. Limitations of the empirical approach are that many regression models have a restricted specification of the relation between variable (e.g. linear, log-linear). Though, increasingly, statistical tools are introduced that can ca the structure, and therefore also part of the processes, of the land use system. For examp multilevel models (Pan and Bilsborrow, 2005) can incorporate a hierarchical structure a autoregressive models (Overmar *et al.*, 2003) can capture spatial processe

The AiC analysis used in the deductive approach depends on the skills and interests of the researcher. Therefore, the AiC analysis is less reproducible than the inductive analys The land use system does not have to be in equilibrium because the processes are obser directly rather than derived from the current land use pattern. Finally, the deductive (A approach does not constrain the specification of the mathematical relations between fac in any way, giving more flexibility to the modell

In this respect it is regrettable that the household information and the ownership relatic with the land were not spatially available for the study area. The distribution of the par and their ownership is an important determinant of the observed land use pattern. By n incorporating this structure the model has the tendency to allocate the land use accordi to the smooth patterns of the suitability maps, while the observed land use pattern sho a more irregular pattern due to land ownership. The AiC analysis of Overm *et al.* (2006) (Chapter 3), from where the deductive approach is derived, is based on a household su and could have been easily incorporated if this information was availabl

The differences described above have their implications for the applicability of the mod to answer questions in research and policy-making. To have some foothold to assess the use of the two modelling approaches for research and/or policy Couclelis (2001) provid

some qualifi cations for both: Besides that both must be built on good science, use good data, and should answer good questions, research models should have a higher degree of scientifi c rigor and should contribute original theoretical insights or technical innova tion. Policy models should preferably be used, verifi ed and validated oft en and should transparent and manipulable and should include key policy variable
As far as the qualifi cations for research are concerned both approaches are quite similar The main diff erence is that the approaches stem from two completely diff erent researcl paradigms. With respect to the policy issues the two approaches do show important dif- ferences. First of all, the inductive approach is more transparent and the CLUE-S model using this approach is validated for several cases (Kok *et al*., 2001; Pontius *et al*., 2005). The AiC approach is dependent on the judgement of the researcher and is therefore less transparent and reproducible. Secondly, the deductive (AiC) approach is more fl exible (manipulable) then the inductive (regression) approach, which has to stick to more rigid model defi nitions. Concerning the inclusion of key policy variables the deductive appro has the advantage of the explicit description of parameters and relations between variab Another advantage that adds to that is that it can include variables like market prices an investments. These variables are constant throughout the study area and can therefore n be included in regression analysis. They are included in the AiC analysis and can therefo be used to study the eff ect of changes in price (through for example subsidy policy) or changes in technology, which can be important policy variables. So, the deductive meth has more options to analyse the eff ects of policies, which are oft en implemented at the macro-level. Potentially, this approach would also enable the modelling of the amount c land use changes and therefore the possibility to make the model more dynami
The scale to which both approaches can be applied is diff erent. In principle the inductiv approach can be applied to any scale (*i.e.* resolution and extent). However, the amount o detail and knowledge about the decision-making structure of actors involved that can b incorporated is limited. The deductive approach as presented in this study relies on de- tailed information about the land managers. To incorporate this information in a spatial explicit model the resolution should be comparable with the size of the decision units of the actors. Aggregating these units to larger grid cells would lead to aggregation proble So, the deductive approach should preferably be applied to the watershed level using a fi ne resolutior
Currently, many eff orts in land use modelling have adopted the multi-agent modelling approach (e.g. Parker *et al*., 2003), which is an agent-based approach in which actors communicate and interact. The deductive approach in this chapter is not a multi-agent model. However, the model can be regarded as an agent-based. It specifi es the decision of farmers in various circumstances, but without communication and interaction and without other actors than farmers involved. By using an actor-decision model to specify land suitability, decisions of the land manager were given a more prominent role in the modelling approach than with a statistical approach. The deductive approach provides more process-information than the inductive approach although the representation of tl actors involved is simplifi ed to one representative act

Both the deductive and the inductive approaches have their own origin and research pa digms and their own advantages and disadvantages as pointed out in this fi nal section. Within the scope of this study, no qualifi cation of the models was presented that was ba on validation of the simulated land use maps. This would not have provided many new insights because the resulting maps were quite similar in this case study. A more import conclusion is that the research question and the nature of the case that is studied determ which approach is most suitable to use. The deductive approach can bett er handle disc tinuities in land use processes and can therefore evaluate a wide range of scenarios, whi can also include new land use types. The inductive approach is easily reproducible and well able rapidly to identify hotspots of land use change. The deductive approach is bett suited for smaller study areas, but needs fi eldwork to implement. The inductive approa can be applied more quickly in larger areas if basic data are availabl