Farmers' decisions and landscape change

an actor-based approach for land-use research

Diego Valbuena

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Preface

This dissertation is another step of my personal interest in studying the interaction between people and environment. I started my post-secondary education in Colombia aiming at understanding the dynamics of plant and animal populations. By the end of my BSc, I was more interested in how natural processes influence the landscape. However, I also wanted to learn about human processes. With this mindset, I went to the Netherlands to study Spatial Planning. For my MSc. thesis, I looked at how human and natural processes have affected processes of deforestation. However, as such processes were taking place at national and regional scale, I felt frustrated with my limited understanding of why people use and change the use of the land. Then the challenge was to study the interaction between human decisions and land-use changes. After some months working at the IRD in France, an opportunity came to start my PhD in Wageningen. The first three years of my PhD were mainly working with my computer and applying different concepts and methods to understand changes in the use of the land. For my last year, I had the chance to go to Australia and apply the knowledge developed during my long days at the office to study land-use processes in a different context. Although this was at times a turbulent process, I was able to be in field and experience for myself many of the concepts and theories cooked in my head. All these experiences are reflected to some extent throughout this dissertation.

During these four years, I have met and worked with many people without whom I would not have been able to write and finish this dissertation. First, I would like to thank my supervisors: Peter for his sharp comments on my work during these four years; Arnold for his invaluable academic support and personal motivation; and Tom for his help to position my thoughts in the general context of land-use research. I would like to acknowledge those who also contributed in the writing of this dissertation. In particular Arend Ligtenberg for his input in Chapter 3 and 4; Clive McAlpine and Leonie Seabrook for their input in Chapter 5 and their support during my stay in Australia; Wieteke Willemen, Erez Hatna, Sytze de Bruin and Derek van Berkel for their suggestions in some of the chapters of this dissertation; and Frans Hermans for translating the summary in Dutch.

I would like to acknowledge Nico Polman, Roel Jongeneel and Tom Kuhlman for allowing me the use of their data. Also, I gratefully acknowledge Hein Korevaar, Jan Tiggeloven and other four regional experts for their support in the understanding and validation of the results of the modelling processes in Chapter 4. My acknowledgements are extended to Michiala Bowen, Paul Dargusch and Rod Fensham for their advice in the development of Chapter 5, as well as to the 30 farmers who kindly spent their time answering my questionnaire in Tara—especially to Lynelle, Warren, Warrik and Diane who also made me feel at home on the other side of the world.

I would like to extend my gratitude for their invaluable company and selfless support to my family, friends and colleagues, especially to Wieteke, Enrique, Jose, Chrystal, Derek, Eefje, Gerd, Henny, Katheleen, Javier, Maartje, Marleen, Martha, Michal, Olivier, Renée, Ricardo and Simon.

Contents

Chapter 1

General Introduction

1 BACKGROUND

Land-use/cover change (LUCC) is a process driven by the interaction of different actors (e.g. farmers, policy-makers and urban developers) and factors (e.g. climate, soil, market and policies) at different organisational, spatial and temporal levels (Moss, 2000; Lambin et al., 2001; Veldkamp and Verburg, 2004). LUCC influences both human and environmental systems. Specifically, LUCC can modify the structure and composition of the landscape, affecting the quality and quantity of services provided by ecosystems to society such as water regulation, food production, habitat and recreation (de Groot et al., 2002; Turner et al., 2007). Uncertainties in the impacts of LUCC on human and environmental systems, together with the need to better intervene in LUCC processes have promoted the development of land-use research (Rindfuss et al., 2004; Turner et al., 2007).

1.1 Land-use research

Land-use research is a common ground for both social and natural sciences. Thus, land-use research is approached from different theoretical and empirical perspectives, depending on the aim and context of the research(er). Following Coleman's approaches to analyse social systems, LUCC processes can be investigated either at an aggregated level or as the result of the interaction between actors and institutions (Coleman, 1990). The former approach focuses on explaining LUCC processes as a whole, based on the analyses of the interactions between social, economic and biophysical processes. This means that aggregated-level approaches do not focus on the actors or institutions involved in LUCC. In contrast, actor-based approaches analyse LUCC as the result of processes that are internal to the system, including the interaction of the individuals and institutions involved in LUCC (Coleman, 1990).

The implementation of aggregated-level or actor-based approaches can be complementary as each approach can generate different information about LUCC processes and can also be used to achieve different objectives (Verburg, 2006; Matthews et al., 2007). For example, these approaches are often implemented and applied to investigate LUCC at different spatial levels. While aggregated-level approaches are often used to analyse global, national and regional processes, actor-based approaches are commonly used to analyse local processes. The main limitation of aggregated-level approaches to analyse local LUCC processes is their inability to represent and link different decision-makers and different organisational units (e.g. field, farm and village). At the same time, the main limitation of actor-based approaches to analyse regional and national LUCC is their inability to identify and include all the interactions and diversity of decision-makers and organisational units at these spatial levels.

However, individual decision-making within regions can be also included and represented. This representation is possible as several socio-economic and biophysical data are available in some regions, including census data, surveys, cadastral data and (historical) land-cover maps. As these datasets can be used as a proxy to represent and characterise individual decision-making within regions, actor-based approaches can potentially be implemented to investigate regional LUCC—specifically when the heterogeneity and/or interaction of individual decision-making are relevant drivers of LUCC processes. Therefore, the focus of this dissertation is on implementing an actor-based approach to explore LUCC in regions, specifically in rural regions.

1.2 LUCC in rural regions

Rural regions are territorial units where small urban centres are surrounded by large low-dense populated areas of open space (Terluin, 2003). In these regions, regional development is determined by the interaction of endogenous (e.g. regional market, accessibility and diversity of decision-making) and exogenous processes (e.g. global market and national policies) (Bowler, 1999; Yeung, 2009). For example, current policies in Europe attempt to reinforce endogenous processes (i.e. multifunctional agriculture) to better prepare regions to respond to exogenous processes (Böcher, 2008). At the same time, a global-oriented economy in Australia strengthen the influence of exogenous processes on the dynamics of regional processes (Sorensen et al., 2007).

LUCC processes in rural regions are often driven by the decisions, actions and interactions of diverse groups of decision-makers and organisations, including policy-makers, urban developers, nature conservation organisations and farmers (Figure 1.1). Yet, human decision-making is an intricate process. Decision-making is influenced by objective and subjective aspects that are embedded in both personal and social processes (Ajzen, 1991; Roccas et al., 2002). For instance, changes in attitudes and values can lead to changes in our behaviour (Grube et al., 1994). Furthermore, people take decisions based on an imperfect knowledge of their socio-economic and biophysical context, meaning that our rationality is bounded (Simon, 1955; Arthur, 1994). As a result of this, uncertainty and risk are often inherent aspects of human decision-making, especially among farmers (Rougoor et al., 1998).

Compared to policy-makers or urban developers, farmers encompass a relatively diverse group of decision-makers. Farmers' decisions influence LUCC processes in rural regions because they often own a relatively large area of land. Farmers' decisions depend on farm(er) factors and endogenous and exogenous processes of rural regions. Farm(er) factors include characteristics of the farmer, her/his family, the farm and the fields. Endogenous and exogenous processes refer to policy regulations, subsidies, and demand. The combination of these factors and processes is reflected in a diversity of decision-making strategies within rural regions (Bowler, 1992; Meert et al., 2005).

To investigate LUCC in rural regions, it is necessary to include the diversity of individual decisions—specifically farmers' decisions-making. A main challenge in land-use research is to simplify and include the diversity of decision-making, and link this diversity to the spatial heterogeneity of the environment where it takes place (Rindfuss et al., 2004). Therefore, this dissertation focuses on analysing LUCC processes as the result of the interaction of different organisational and spatial levels, namely the spatial interaction between farm(er) factors and endogenous and exogenous processes of rural regions.

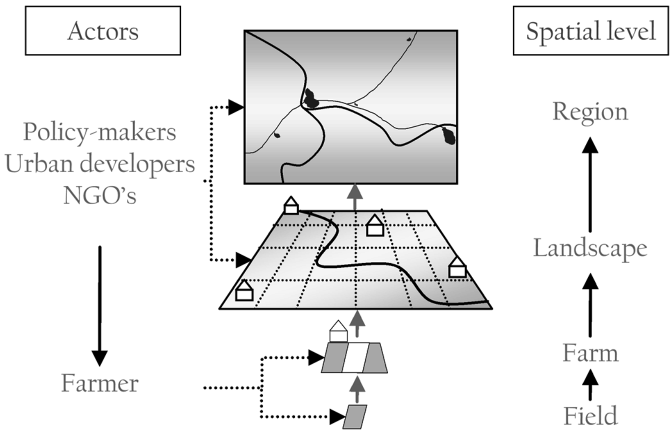


Figure 1.1. Actors and spatial levels related to decision-making in rural regions.

1.3 LUCC modelling

As a result of the interactions and feedbacks between social and biophysical actors and factors at different organisational, spatial and temporal levels, the analysis and understanding of the patterns and dynamics of LUCC processes cannot be carried out by using simple direct measurements (Veldkamp and Lambin, 2001; Parker et al., 2003; Turner et al., 2007). Computer-based modelling tools can support land-use research. These tools can be used to manipulate, combine, analyse, simulate and visualise the components of LUCC processes (Batty, 1991; Halpin, 1999; Verburg et al., 2004).

Related to actor-based and aggregated-level approaches to investigate LUCC processes, different modelling techniques have been developed and applied to land-use research (Briassoulis, 2000; EPA, 2000). The choice of using a particular modelling technique depends on both theoretical and practical aspects such as research approach, scientific discipline, research question and available data. As this dissertation investigates LUCC in rural areas as a result of the response of farmers to socio-economic and biophysical processes, an actor-based modelling technique is required.

Agent-based modelling (ABM) is an actor-based technique to represent, analyse and explore farmers' decision-making processes and their interaction with their socio-economic and biophysical context (Balmann, 2000; Ligtenberg et al., 2001; van der Veen and Otter, 2001; Bonabeau, 2002; Sawyer, 2003; Evans and Kelley, 2004). In this way, ABM represents individual decision-making units and their environment. These units or agents can be heterogeneous in terms of experience, socio-cultural background, economic situation, goals and family structure. Agents represent autonomous decision-makers as they can take their own (land-use) decisions based on objective and subjective rules. Finally, agent behaviour can be dynamic as they are able to learn and adapt to different situations (Ferrand, 1996; Bonabeau, 2002; Parker et al., 2003; Sawyer, 2003; Crawford et al., 2005). Because of its capacity to represent individual decision-makers and their environment, ABM is used as the main modelling technique in this dissertation.

The development of ABM has become a common practice in land-use research (Matthews et al., 2007; Rindfuss et al., 2008). ABM is often developed to be applied to a particular study area, making difficult the comparison between models and modelling results (Parker et al., 2008). The development of these models is facilitated by the use of ABM platforms (Railsback et al., 2006; Nikolai and Madey, 2009). These platforms make available standardised software designs and tools to develop models (Railsback et al., 2006)

In spite of the existence of generic platforms and the increasing use of ABM in land-use research, ABM is not commonly implemented and applied to study regional LUCC processes. Such an implementation and application still face conceptual and methodological challenges. Recent studies have also addressed some of these challenges (Happe et al., 2006; Brady et al., 2009; Happe et al., 2009; Kaufmann et al., 2009; Piorr et al., 2009). The first challenge is that, according to Berger et al. (2006), few ABM models dealing with LUCC processes are empirically parameterised. This has limited the use of ABM as ex-ante tools to analyse and explore the impact of policies on LUCC processes. Another challenge is that ABM is mainly applied to analyse and simulate LUCC processes at local levels (e.g. Acosta-Michlik and Espaldon, 2008; Le et al., 2008). This means that ABM is not often applied to simulate LUCC at a regional level. The parameterisation of such a regional ABM faces several methodological challenges, such as formulation, empirical parameterisation and validation. An additional challenge is that ABM aimed to analyse and simulated LUCC processes at regional levels often excludes the inherent diversity of decision-making among farmers (e.g. Ligtenberg et al., 2004). Finally, the spatial heterogeneity of the environment where LUCC processes take place is often oversimplified in ABM, including the socio-economic and biophysical characteristics of the land and the spatial structure of the landscape.

2 CONTENTS

2.1 Objectives

The implementation and application of actor-based approaches to analyse and simulate LUCC in rural regions faces several methodological and conceptual challenges related to: (i) the diversity of decision-making, (ii) the interaction between decision-making and spatial LUCC processes, and (iii) the development of empirically-parameterised regional ABM that can be used for policy analysis. Addressing these conceptual and methodological challenges of implementing and applying these approaches can have implications not only in land-use research, but also in analysing land-use policies in rural regions. The aim of this dissertation is twofold. The first part aims at developing methods to take account of individual decision-making related to LUCC and the emerging spatial structure of the landscape. The second part aims at using these methods to include the diversity of individual decision-making in the analysis of different (land-use) policies in rural regions. These objectives are formulated into three research questions:

- How to characterise the diversity of farmers' decision-making within rural regions with respect to land-use change?
- How to represent and simulate changes in landscape structure in rural regions as a result of farmers' decision-making?
- How to apply this knowledge to explore and analyse the effect of land-use policies on the landscape structure in different study areas?

2.2 Study areas

To answer the research questions, the concepts described in this dissertation were applied to two different rural regions: the Achterhoek in the Netherlands and the Tara region in Australia.

2.2.1 *The Achterhoek, the Netherlands*

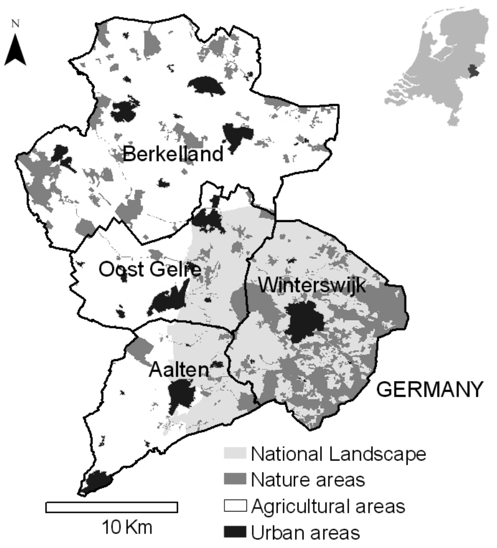


Figure 1.2. First study area: location and land-cover.

The described concepts were applied to the Achterhoek region in Chapter 2, 3 and 4 of the dissertation. The Achterhoek is a rural region located in the eastern part of the Netherlands (51°51′N, 6°24′E to 52°10′N, 6°48′E; Figure 1.2). This region covers an area of 60.650 ha. Dairy production is the dominant agricultural sector in the region. In 2005, there were almost 2300 farms with an average farm size of 20 ha (Farm Accountancy Data Network). The region is temperate, dominated by sandy soils. Part of this region is classified as a cultural-historic landscape where small-scale agriculture and nature areas are closely related providing a particular cultural, recreational, tourist, ecological and economic value to the region (Provinciale Staten van Gelderland, 2005b). The spatial structure of the landscape has been the result of the interaction between biophysical and socio-economic factors and processes, such as soil characteristics, water availability, land tenure regimes, accessibility and the demand for industrial labour (Benvenuti, 1961; Wildenbeest, 1989; Mastboom, 1996).

In the last decades, social changes such as the increasing environmental awareness and the growing demand for recreation and tourist accommodation have taken place. Additionally, legislative changes have occurred such as the establishment of milk quotas, restrictions on manure applications, and compensatory payments for nature and landscape conservation. These social and legislative changes have influenced the rural dynamics of the region (Provinciale Staten van Gelderland, 2005a).

2.2.2 *Tara region, Australia*

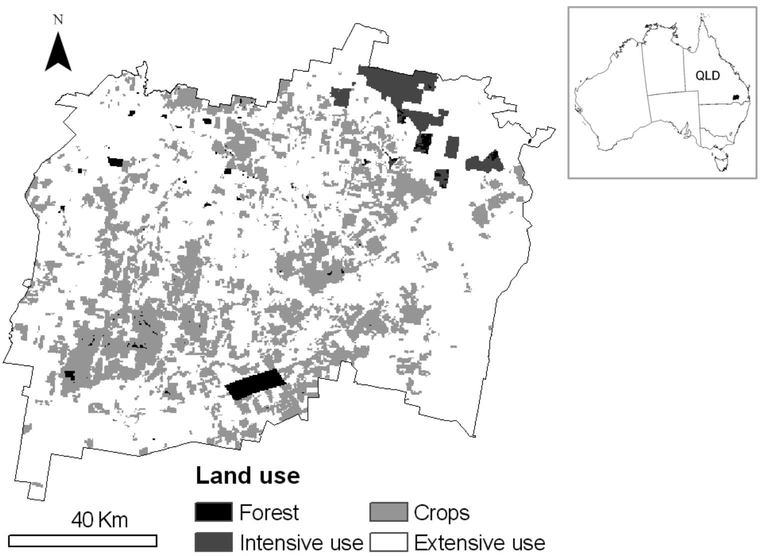


Figure 1.3. Second study area: Location and land-use map.

The methods for characterising the diversity in decision-making and the modelling framework were applied to the Tara region in Chapter 5 of the dissertation. Tara is a rural region located in the south-eastern part of Queensland, Australia (26°54′S, 149°24′E to 28°17′S, 150°53′E; Figure 1.3). This region covers an area of ~1.2 million hectares. The agricultural sector in the Tara region includes grain, beef and wool. In 2006, there were almost 500 farms with an average farm size of 2000 ha. The region is subhumid, dominated by clay plains and covered mainly by brigalow (Young et al., 1999)—a common name for *Acacia harpophylla* F. Muell. ex Benth. and forests and woodlands that it dominates (Dwyer et al., 2009). Once cleared, brigalow can develop in very dense patches of secondary vegetation that hinders agricultural practices (Scanlan, 1991).

During the 1950s and early 1960s the Queensland government promoted the settlement of the region and the clearing of brigalow to establish improved pasture for grazing (Seabrook et al., 2006). Since then, the fertile areas of the region have been cleared and developed, while less suitable areas are used for extensive grazing, forestry and nature protection (Environment Australia 2000). Remnant native vegetation is highly fragmented and disturbed. Less than 40% of the native vegetation remains in the region, mostly occurring on low fertility sandstone landforms (Wilson et al., 2002; Seabrook et al., 2006).

2.3 Outline of the dissertation

This dissertation consists of 6 chapters (Figure 1.4), including this general introduction. Chapter 2 and 3 are the conceptual core of the dissertation. Chapter 2 describes and illustrates the use of agent typologies to simplify and include the diversity of decision-making of rural regions. Chapter 3 demonstrates a generic agent-based modelling framework to analyse and simulate LUCC in rural regions, which contains the diversity of decisions described in Chapter 2.

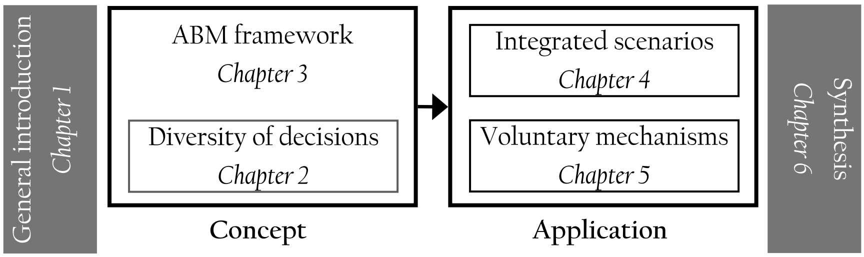


Figure 1.4. Schematic outline of this dissertation.

Chapter 4 and 5 comprise the application of the concepts described before. In chapter 4, the agent-based framework is used to explore how the response of farmers to changes in socio-economic processes at national and global levels (i.e. integrated scenarios) can affect the landscape structure in a rural region in the Netherlands. In chapter 5, this framework is applied to explore how farmers' participation in voluntary mechanisms to restore native vegetation can influence the landscape in a rural region in Australia. Based on the application of the modelling framework, Chapter 6 presents the main findings of this dissertation, as well as the discussion of the research questions and the contribution of this dissertation to land-use research and policy-making processes.

Chapter 2

Regional farming strategies: an agent typology

Abstract

LUCC in rural regions is often the cumulative result of individual decisions-making, especially farmers' decisions. To understand and simulate LUCC as the result of individual decisions, agent-based modelling (ABM) has become a popular technique. However, the definition of agents is not often based on real data, ignoring the inherent diversity of farmers and farm characteristics in rural regions. The aim of this chapter is to describe an empirical method that defines an agent typology and allocates agents into the different agent types for an entire region. This method is illustrated with a case study in the Netherlands, where processes of farm cessation, farm expansion and diversification of farm practices take place. Five different agent types were defined and parameterised in terms of farmers' views, farm characteristics and location. Despite its simplicity, this empirical method captures several relations between farmers' views, farm characteristics and land-use decisions and strategies. This approach is a step forward in ABM for land-use/cover change to include the diversity of land-use decisions and strategies in regional studies by empirically defining, parameterising and allocating different agent types.

Based on: Valbuena D, Verburg PH, Bregt AK. 2008. A method to define a typology for agent-based analysis in regional land-use research. *Agriculture, Ecosystems and Environment.* 128:27-36

1 Introduction

Land-use/cover change (LUCC) is a complex process caused by the interaction between natural and social systems at different temporal and spatial levels (Lambin and Geist, 2001; Rindfuss et al., 2004). In rural regions, LUCC is related to the dynamics of the agricultural sector in general, and those of the farming systems in particular. However, each farming system is different (Köbrich et al., 2003), reflecting the diversity of human's behaviour and decisions. This diversity is not only influenced by the complexity of the human behaviour itself (Simon, 1955; Rokeach, 1968; Ajzen, 1991; Arthur, 1994), but also by both farm and regional factors such as farmer's experience, family structure, economic and technical resources, and the socio-economic context where these decisions occur (Gasson, 1973; Ilbery, 1978; Evans and Ilbery, 1989; Willock et al., 1999b; Knowler and Bradshaw, 2007).

An approach to analyse and simulate human decisions in LUCC is the use of ABM (Parker et al., 2003; Brown, 2005; Matthews et al., 2007; Robinson et al., 2007). By using autonomous and heterogeneous agents, ABM explicitly deals with the diversity of land-use decisions. In this way, ABM copes with the limitation of most of the land-use models implemented at a regional level (Balmann, 2000; van der Veen and Otter, 2001; Bonabeau, 2002; Sawyer, 2003; Evans and Kelley, 2004; Verburg, 2006), which often use a single response function throughout the study area, assuming that human decision-making is a homogeneous process (e.g. Fohrer et al., 2002; Soares-Filho et al., 2002; Verburg et al., 2002; Luijten, 2003).

Agents can be defined and parameterised in many different ways, depending on the objectives of ABM itself (Janssen and Ostrom, 2006; Robinson et al., 2007). For example, agents can represent broad groups of stakeholders such as landowners, government or environmentalists (e.g. Ligtenberg et al., 2004; Monticino et al., 2007); socio-economic units such as households (e.g. Evans and Kelley, 2004; Matthews, 2006); or organisational units such as farms (e.g. Balmann, 2000; Happe et al., 2006). The decision-making process of agents needs to be specifically parameterised by decision rules. These rules can be defined based on either artificial or empirical data. Agent parameterisation with artificial data is a common approach in ABM (Berger and Schreinemachers, 2006). Although improving the theoretical insight into LUCC dynamics, the validity of such artificial agent definition is often difficult to assess (Gimblett, 2002; Parker et al., 2003). On the other hand, agent parameterisation with empirical data can facilitate the understanding of real LUCC processes. Still, most studies using empirical data to define and parameterise agents rely on intensive data gathering (e.g. Bousquet et al., 2001; Huigen, 2004; Castella et al., 2005; Jepsen et al., 2006).

At a regional level, intensive data gathering is limited because of the large number of agents. Despite the diversity of farming systems at such spatial level, general farming strategies can be distinguished, what Bowler (1992) define as "paths of development" (see also Wilson, 2007). These general pathways are a simplification of how farming can develop in a certain area (Meert et al., 2005). A relevant approach to analyse the diversity in decision-making of farmers is to formulate typologies (McKinney, 1950; Jollivet, 1965; Escobar and Berdegué, 1990; Perrot and Landais, 1993a; van der Ploeg, 1994). A typology is a tool to simplify the diversity of farmers and farming strategies. This means that a typology is an artificial way to define different groups based on specific criteria in order to organise and analyse reality (McKinney, 1950; Jollivet, 1965). The criteria to construct a typology, as well as to evaluate it, primarily depend on the objectives of its implementation (Escobar and Berdegué, 1990). Different kinds of typologies for agents in rural regions can be distinguished based on their aim. For example, some typologies intend to understand the whole farming process, which include the most relevant farm(er) characteristics (e.g. Escobar and Berdegué, 1990; Perrot and Landais, 1993b; van der Ploeg, 1994). Other typologies aim to analyse the underlying reasons of certain farmers' decisions (e.g. Morris and Potter, 1995; Fish et al., 2003; Guillaumin et al., 2004). Finally, other typologies aim to explain the different production strategies that farmers developed or might develop (e.g. Ondersteijn et al., 2003; de Lauwere, 2005; Vanclay et al., 2006; Van Doorn and Bakker, 2007). Nevertheless, most of the current typologies do not account for the spatial linkage in which land-use decisions are embedded (Landais, 1998).

The aim of this chapter is to describe an empirical method to formulate define and parameterise different agent types for use in ABM at a regional level. This method first formulates an agent typology and subsequently distributes spatially the defined agent types in the entire region. After describing the general method, this chapter illustrates the method with a case study in the East of the Netherlands where processes of farm diversification and farm expansion are taking place. Finally, this chapter discusses the advantages and the limitation of the proposed method, including its potential applications in ABM, land-use research and policy-making processes.

2 Method

To include the diversity of land-use decisions and strategies at a regional level in ABM, we need first to simplify the diversity between all individual agents by formulating an agent typology (Typology Formulation, Figure 2.1), and thereafter, we need to distribute spatially the defined agent types in the region (Agent Type Spatial Distribution, Figure 2.1).

2.1 Typology Formulation

In the first part of the method, the diversity of land-use decisions and strategies is simplified by defining and characterising different agent types in the region based on four steps (Figure 2.1).

Step 1. Agent modelling objectives

Before simplifying the diversity of farmers' decisions and strategies, we need to define clearly the aim of such simplification. In the case of ABM at a regional level, we need to establish what the agent modelling objectives are: do we want to understand and simplify the whole LUCC dynamics of the region? Are we interested only in simulating a particular process? Or are we interested in the reasons to follow a particular land-use management strategy?

Step 2. Criteria selection

The definition of the agent modelling objectives facilitates the selection of different criteria that are used to define and parameterise the agent typology. The selection of these criteria not only reflects the objective of the research and the scientific approach (e.g. Berdegué and Escobar, 1990), but also defines how the diversity of land-use decisions and strategies is simplified and included in ABM. Still, such criteria should not rely only on quantitative analyses, but they also need to have a meaning to the social reality of LUCC (Perrot and Landais, 1993a; Landais, 1998). Further, these criteria generally need to describe the views and perceptions of the agent as well as their socio-economic situation and context. Related to views and perceptions, Burton and Wilson (2006) argue that farmers can have different identities (e.g. agricultural producer and diversifier). In this way, a typology can be defined by using a combination of identities. Data to define these identities are often not available for all agents in a region because restrictions on data accessibility or the data do not even exist. Therefore, such data can be gathered by using a sample survey.

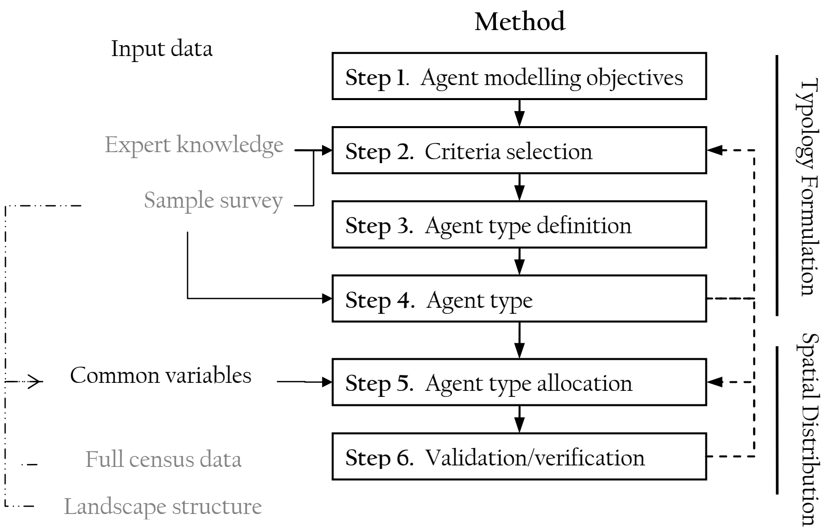


Figure 2.1. Diagram of the method.

Step3. Agent type definition

The definition of different agent types primarily depends on the selected criteria. Different methods to construct typologies have been described (e.g. Escobar and Berdegué, 1990; Landais, 1998; van der Ploeg, 2003). For example, a typology can be constructed using qualitative (e.g. Guillaumin et al., 2004; Schmitzberger et al., 2005) or quantitative analyses (e.g. Wilson and Hart, 2000; Köbrich et al., 2003; Kristensen, 2003; de Lauwere, 2005); attitudinal (e.g. Fairweather and Keating, 1994; Morris and Potter, 1995) or socio-economic variables (e.g. Commandeur, 2005; Schmitzberger et al., 2005); and scientist knowledge (e.g. Perrot and Landais, 1993b; van der Ploeg, 1994) or participatory processes (e.g. Girard, 2006). The choice of a particular analysis depends on the selected criteria and available data.

Step 4. Agent type parameterisation

In this step, agent types are described in terms of views and strategies relevant to the ABM. This is a step to understand the differences between agent types based not only on views and decisions, but also on their socio-economic situation and context. To assess whether these differences are significant, statistical analyses are used. Most of the attitudinal and socio-economic variables used to parameterise agent types are included in the sample survey. Finally, some of these variables can be also used as common variables (see below).

2.2 Agent Type Spatial Distribution

In the second part of the method, all agents in the study area are classified as one of the defined agent types. Further, the method is validated and verified.

Step 5. Agent type allocation

Although census data of the entire population of a region are often available, the level of detail and/or accessibility of such data are often limited. Therefore, these data are not used to define the different agent types when a representative sample survey is available. The use of common variables between a sample survey, census data and additional socio-economic and biophysical data allows us to classify all agents into one of the defined agent types (Figure 2.1). Although spatial variables can be used to define and parameterise the different agent types, it is in this step that agent types are explicitly linked to the landscape. Finally, depending on the available data for the region, different quantitative analyses techniques can be used to classify agents, such as multivariate analyses.

Step 6. Validation/verification

The definition and allocation of the different agent types (step 3 and 5, Figure 2.1) may result in some degree of overlap between agent types and consequently uncertainty about the definition of the variables due to both the complexity of land-use decisions and the limited data availability. For this reason, it is necessary to validate these steps and determine the level of uncertainty of the results. Based on this validation/verification process, early steps of the method might need to be modified. Participatory approaches could be used to validate an agent typology (e.g. Girard, 2006). However, agent types are an abstract representation of reality which makes it difficult for people to recognise themselves in the agent types as defined and therefore hampers such a validation.

3 APPLICATION

In this part, the proposed method is illustrated with the Achterhoek. The Achterhoek is a rural region in the eastern part of the Netherlands. This region covers an area of 60.650 ha. Dairy production is the dominant agricultural sector in the region. Currently, processes of farm cessation, farm expansion and diversification of farm practiceses are taking place (see section 2.2, Chapter 1).

3.1 Input Data

The application of the proposed method is based on a sample survey carried out during winter 2004 (Jongeneel et al., 2005), census data of the entire population in the study region (Farmer Accountancy Data) and additional socio-economic and biophysical spatial data. The sample survey included 333 farmers and it was originally carried out to explore the factors that determine the diversification of farm practices including farmer's views (positive, neutral and negative) and structural variables such as the existence or not of a successor, production scale, degree specialisation of the farm and past land-use changes (Jongeneel et al., 2005). The census data include only a limited number of structural variables such as agribusiness type, production scale, cultivated area, head farmer's age and labour, and no attitudinal variables. Finally, additional spatial data include: groundwater table, altitude, proportion of nature and historical areas, farm density, production scale and cultivated area.

To simplify the parameterisation and allocation of the different agent types, some variables were grouped. In particular, agribusiness type and category of production scale were defined based on CBS (Statistics Netherlands) terminology. Four main agribusiness types from the Dutch version of the Community Typology were distinguished for the study area: arable, livestock, intensive livestock and other farms. Also, based on the production scale, farms were divided into four main categories: hobby (3-20 dsu), small (20-50 dsu), medium (50-100 dsu) and large farms (> 100 dsu). Dsu or Dutch size units represent the economic size of a farm including the amount and use of the land; in 2005, a dsu was equal to 1400 Euros.

3.2 Typology formulation

Step 1. Agent modelling objectives

The agent modelling objective is to understand the different strategies that farmers have followed and/or might follow in terms of farm diversification practices and farm expansion.

Step 2. Criteria selection

Because these land-use decisions often depend on individual decisions, the criteria to define this typology should include farmers' views or willingness (Siebert et al., 2006). In particular, views on expansion of production scale as a future alternative, diversification of farm practices as an additional income and participation in compensation schemes for nature and landscape conservation practices were selected. At the same time, socio-economic variables can implicitly represent different farming strategies. This is partly related to the farmer's ability to carry out certain action (Siebert et al., 2006). Specifically, farming is an important source of income for some farmers or it is simply a hobby for others. This distinction has an influence in decisions concerning the diversification of farm practices and the expansion of their farms (e.g. Primdahl, 1999; Kristensen, 2003; Schmitzberger et al., 2005). Therefore, both willingness and ability are used as criteria to define the different agent types.

Step 3. Agent type definition

Based on an analysis of the diversity in views and socio-economic conditions, a "classification tree" was chosen as most appropriate method to construct the typology in this case study. This tree is based on Boolean statements defined in the criteria described above: production scale larger than 20 dsu, view on expansion of the production scale and on participating in compensation schemes. The results of this classification tree were supported by explorative analyses, including regression, factor and cluster analysis.

Step 4. Agent type parameterisation

After agent types were defined, they were parameterised based on additional variables such as age, education, cultivated area, type of agribusiness, successor, past land-use decisions, membership of different organisations, knowledge about different agricultural projects, etc. To define whether the differences of the metric variables between agent types were significant, analysis of variance (ANOVA) was used.

3.3 Agent Type Spatial Distribution

Step 5. Agent type allocation

In this case study, census data were available for the entire agent population. This means that socio-economic data of each real agent and its exact location were available. Therefore, a classification of these agents into agent types could be made using the common variables between the survey data and census data. The common variables included: age, agribusiness type, production scale and landscape structure.

The analysis of the landscape structure was carried out at postcode level (average area 550ha), at which the location of the farms of the survey was known. To calculate the relation between these spatial variables, Pearson correlation analyses were carried out. Finally, to assess whether the landscape structure was significantly related to the agent typology or farming decisions (non-parametric variables), Kruskal-Wallis tests were carried out (for detailed information on these analyses see Legendre and Legendre, 1998; Lesschen et al., 2005).

To classify the different agent types a classification tree was calculated using the CRT growing method (SPSS 15.0). This approach is similar to the one discussed by Speybroeck et al. (2004), who selected as splitting criteria the 'Gini method' because it performs the best. To avoid overfitting the model, the size of parent and child nodes was limited to 20 and 4 respectively. The definition of these sizes was related to both the size of the sample survey and the validation procedure (see below). The advantages of using classification trees are that it allows combining metric and non-metric variables, and including non-linear relationships.

Step 6. Validation/verification

To assess the uncertainty of the classification process, a cross-validation method for the classification tree was implemented (SPSS 15.0). With this method, the dataset was divided into 25 sub-samples. Each sub-sample was classified based on the results of the classification tree of the other 24 samples. The proportion of cases that were correctly classified was calculated for the 25 runs. Further, the classification tree assigns to each agent the probability to belong to each agent type, selecting the type that has the highest probability. To see whether this probability was the same throughout the landscape, a map of the mean highest probability was calculated.

4 RESULTS

In the study area, there is a tendency towards the reduction of the production scale. While around 7% of farmers belonged in 2005 to a higher category of production scale than in 2001, almost 30% belonged in 2005 to a lower category. Furthermore, according to the CBS data, between 2001 and 2005 there was a decrease of 12% of farms in the entire province (around 1950 farms).

4.1 Typology formulation

As it was mentioned before, the agent modelling objective in this case study is to understand and simplify the different strategies that farmers have followed and/or might follow in terms of farm diversification practices and farm expansion (step 1).

Two different criteria to define agent types were selected: production scale and farmers' views (step 2). This first distinction reflects to some extent the role of agriculture for a farmer (life-style vs. life-style and production). It also distinguishes farmers with very small farms who might have a relative less relevant role in landscape dynamics than those with bigger farms. This is partially reflected by the fact that most farmers with hobby farms (<20dsu.) had similar views: they were not willing to expand their production scale (84%) and they did not have a negative view on compensation schemes for nature and landscape conservation practices (95%).

The second distinction reflects the current and potential probability that a farmer diversifies farm practices and/or expands the production scale of his/her farm. In fact, around 80% of those who think that a future alternative is to increase the production scale have increased the area of their farm and the milk quota between 2001 and 2005. On the other hand, around 17% of those who have a negative view on participating on compensation schemes have diversified farm practices, compared to 32% of those with neutral view and 51% of those with a positive view. However, there were not differences in terms of farm diversification between those farmers with a negative or neutral view on participating in such schemes.

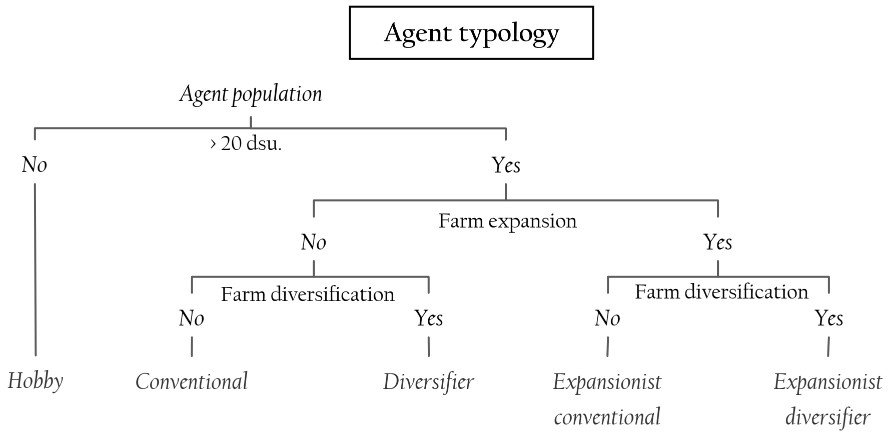


Figure 2.2. Qualitative classification tree to define the different agent types.

Based on these two criteria and the fact that most farmers did not disagree on seeing diversification of farm practices as a means to obtain more income, five different agent types were defined (step 3): Hobby (H), Conventional (C); Diversifiers (D); Expansionist-conventional (EC); and Expansionist-diversifiers (ED) (Figure 2.2).

These agent types were parameterised based on several socio-economic characteristics (step 4) (Table 2.1, 2.2, 2.3 and 2.4).

- *Hobby*: agents with different ages and with different agribusiness types who own very small farms and who normally have an off-farm job. They are unlikely to expand the production scale of their farms. In fact, a relatively high proportion of them have decreased the size of their farm and the milk quota. Moreover, the probability that they would stop farming is relatively high, whereas the probability that they participate in different associations or that they know about different agricultural projects is relatively low. Also, they are unlikely to participate in compensation schemes. However, the probability that they implement other farm practices such as tourism and recreation is relatively high.
- *Conventional*: in general, agents who are not young and who do not own arable farms. They own most of their land and they have different categories of production scale. Still, they are unlikely to expand their production scale. The probability that they stop farming is high and that they participate in different associations or that they know about different agricultural projects is relatively low. Although they do not have a positive view towards compensation schemes, the proportion of diversification of farm practices is relatively higher than that of *hobby*.

Table 2.1. Agent type parameterisation: production strategies.

Agent type	Stop farming	Increase production	Decrease production	Diversify farm practices	Compensati on schemes	Tourism and recreation
H	+	-	+	-	-	+
C	+	-	+	+	+	+
D	+	-	+	+	+	+
EC	-	+	-	-	-	-
ED	-	+	-	+	+	+

Table 2.2. Agent type parameterisation: age and farm characteristics (mean).

Agent type	No.	Age*	Agricultural income (prop)	Production scale (dsu)	Cultivated area (ha)	Labour (h/week)	Lab. Family (h/week)	Owned land (prop)
H	43	49	.58	10.5	15.1	25.6	12.6	.85
C	44	52	.81	96.4	24.7	40.0	28.5	.76
D	34	50	.71	77.6	24.0	39.7	17.5	.70
EC	115	48	.71	125.0	36.2	42.3	32.8	.66
ED	48	48	.77	143.2	39.8	41.9	40.1	.68

*Excluding age, all the variables were significantly different between agent types (ANOVA, $p < 0.05$).

Table 2.3. Agent type parameterisation: education, off-farm job, farm diversification and expansion (percentages).

Agent type	Education: low level	Off-farm job	Divers. Farm	Nature & landscap	tourism recreation*	Farm size**		Milk quota**	
						More	Less	More	Less
H	36.8	56.1	22.0	19.5	7.3	7.3	12.2	14.6	22.0
C	35.7	20.5	34.1	31.8	4.5	34.1	11.4	31.8	9.1
D	26.4	23.5	52.9	47.1	5.9	41.2	17.6	26.5	14.7
EC	18.7	19.5	21.2	20.4	.9	66.4	1.8	76.1	.9
ED	10.6	23.4	46.8	46.8	4.3	70.2	0	68.1	4.3

*Excluding tourism, all these variables were significant different between agent types (Phi analysis, $p <0.05$). ** Percentage of farmers who made changes in the last five years.

Table 2.4. Agent type parameterisation: attitudes, membership and acquaintance with projects (percentages).

Agent type	Stop farm	Agriculture org.	Local parties: improve agricultural sector	Agriculture association: landscape management	Acquaintance of different agriculture projects
H	34.1	46.3	7.3	24.4	65.9
C	36.4	77.3	6.8	13.6	61.4
D	32.4	76.5	26.5	47.1	88.2
EC	6.2	89.4	18.6	16.8	84.1
ED	4.3	91.5	34.0	53.2	85.1

- *Diversifiers*: agents who are neither young nor old, mainly with livestock and intensive livestock farms. They own small and medium farms, and they normally own most of their land. They are unlikely to expand their production scale, and many of them have decreased their farm size and their milk quota. The probability that they stop farming, that they participate in different associations, that they know about different agricultural projects and that they diversify farm practices is relatively high.

- *Expansionist-conventional*: agents with different ages, and with livestock and intensive livestock farms. They own medium and large farms and only half of them own most of their land. The probability that they increase the production scale of their farms is high, and that they decrease the production scale or that they stop farming is low. Their participation in agricultural organisations is high, excluding those for nature and landscape conservation. The probability that they diversify farm practices is low.
- *Expansionist-diversifiers*: agents who are relatively young with relatively high level of education. They own medium and large farms with different agribusiness types. The probability that they increase the production scale of their farms is high and that they stop farming is low. Their participation in agricultural organisations is the highest. The probability that they diversify farm practices is also high, mainly their participation in compensation schemes.

4.2 Agent Type Spatial Distribution

The common variables include age, agribusiness type, production scale and landscape structure. In terms of age, around 40% of the agents of type ED are less than 40 years old and of type EC are between 40 and 50 years old. In terms of production scale, almost 42% of agents of type D own small farms, while more than 60% of type EC and ED own large farms. In terms of agribusiness type, most of the arable farms belong to agents of type H, while about 82% of the agents of type EC own a livestock farm and relatively more intensive farms belong to agents of type C and D. Finally, about half of the agents of type H are located in postcode areas with a proportion of nature areas between 5-20%, while only 29% of the agents of type ED are located in those areas. Also, around 50% of agents of type H and 41% of those of type D are located in areas with small-scale agriculture—postcode areas where fields smaller than 2ha represent more than 20% of the total area—while only 32% of those of type ED are also located in those areas.

The landscape structure is significantly related to the diversification of farm practices. Agents who have diversified farm practices tend to be located in postcode areas higher in altitude ($Z=-1.93$ $p<0.1$) and with more nature ($Z=-2.02$ $p<0.05$) where the average field size is relatively smaller ($Z=-3.45$ $p<0.01$) than those who have not diversified. At the same time, some of these variables are correlated. Nature tends to be located in higher areas ($r=0.54$, $p<0.01$) where the groundwater table is lower ($r=0.25$, $p<0.05$). Also part of the nature areas has a historical value in the study area ($r=0.36$, $p<0.01$). On the other hand, postcode areas with a high nature density tend to have a higher farm density ($r=0.55$, $p<0.01$), more hobby farms ($r=0.27$, $p<0.05$), less intensive livestock farms ($r=-0.26$, $P<0.05$) and more farms with tourism and recreational facilities ($r=0.30$, $p<0.01$).

The classification process shows that each type is not equally distributed throughout the region (step 5). This distribution is partly related to the spatial structure of the landscape: small-scale agriculture towards the South-West and large-scale agriculture in some parts in centre of the study area (Figure 2.3). For example, the density of hobby farms is higher near urban and nature areas (Figure 2.3.A), where small-scale agriculture often takes place. In contrast, the density of EC and ED is higher in areas where large-scale agriculture occurs (Figure 2.3.D and 2.3.E).

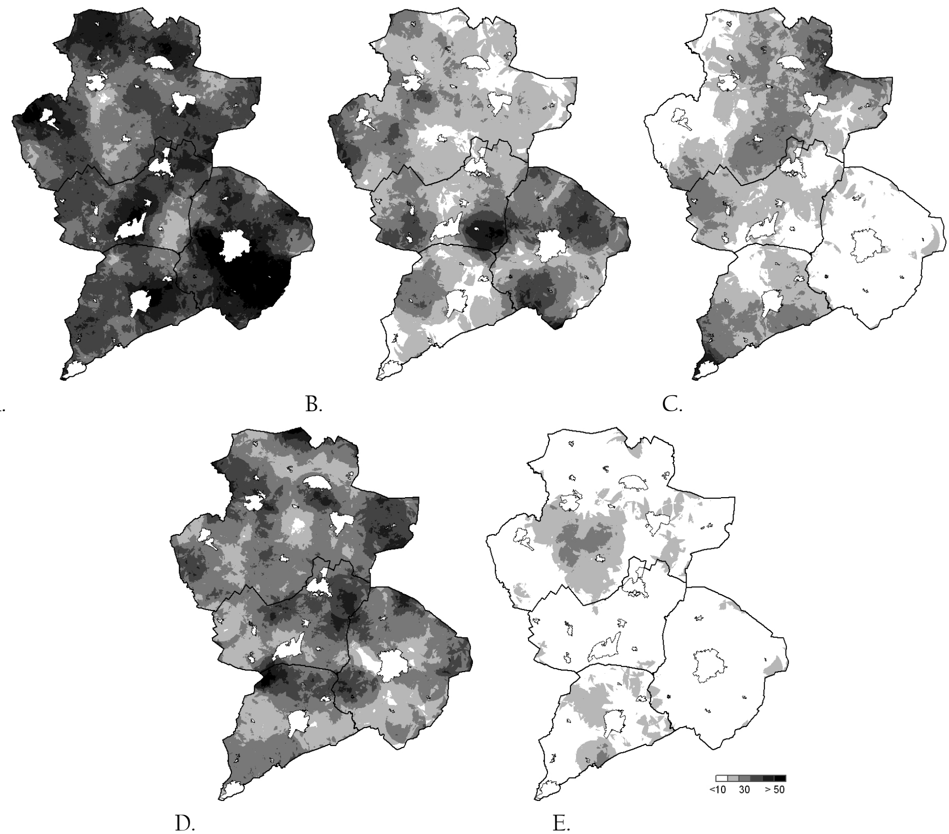


Figure 2.3. Density of agents of each agent type: Hobby (A); Conventional (B); Diversifiers (C); Expansionist-conventional (D); Expansionist-diversifier (E). White polygons are urban areas.

Excluding hobby farms, the cross-validation of the classification tree (step 6) shows that around 50% of the agents of the survey were correctly classified using this approach. This percentage is higher than if the entire allocation/classification process is carried out randomly. This degree of uncertainty was mainly caused by the overlap between different agent types. This overlap is related to the distribution of the common variables within each agent type. For example, the overlap between agent types EC and ED was relatively high, making the distinction between these two types less clear than in other cases. This uncertainty is reflected differently among the different agent types. As it was mentioned before, an agent is assigned to the type in which he obtained the highest probability. Thus, the highest probability that an agent belong to a particular type varied among types. In particular, about 66% of the agents of EC had a probability to belong to this agent type lower than 60%, while about 88% of those of ED had a probability higher than 80%. Because the agent distribution is not homogenous throughout the region, then the uncertainty of the classification process throughout the region is also heterogeneous (Figure 2.4).

Figure 2.4. Highest probabilities to belong to a particular agent type. White polygons represent urban areas.

Several differences can be distinguished when looking at the relative amount of agents and the means of age, production scale and cultivated area of each agent type in the results of the construction of the agent typology (Table 2.3) and in the results of the classification procedure (Table 2.5). The mismatch between these two set of results indicates that the sample survey does not completely represent the entire population. In fact, small-scale dairy farms (mainly hobby farms) are underrepresented, whereas large-scale dairy farms and young farmers are overrepresented in the survey.

Table 2.5. Average of the means and standard deviation of the allocated agent types.

Agent type	No.	Age	Production scale (dsu)	Cultivated area (ha)
H	735	59 (12)	9.1 (4.5)	6.8 (4.5)
C	403	54 (12)	69.7 (41.8)	23.5 (14.2)
D	296	55 (11)	35.3 (10.6)	14.5 (9.6)
EC	522	54 (12)	113.0 (60.3)	38.0 (17.7)
ED	136	52 (11)	126.8 (62.8)	28.8 (21.9)

5 Discussion

The construction of an agent typology is the first step to include the diversity of farmers' decision-making in land-use research at a regional level, in particular in ABM. The linkage between this typology to the landscape allows us to combine different datasets at different scales. These different datasets can be also seen as individual empirical methods to define agent-based models, including survey samples, census and GIS data (Janssen and Ostrom, 2006; Robinson et al., 2007). Other empirical methods, such as interviews, experiments and observations could be as well included to define an agent typology. However, it is the combination of these different input data that allows allocating empirically the different agent types through an entire region, where there is normally a lack of detailed data. Consequently, this approach makes it possible to simplify and include the diversity of farming systems and individual decisions in ABM at a regional level.

The method described in this chapter has some limitations. The different agent types distinguished in this chapter overlap in terms of farm(er) characteristics and decisions. Although characteristics such as age and agribusiness type might be important indicators of farmers' views, perceptions and decisions, these are interacting with so many other variables that they are unlikely to discriminate perfectly agent types. In other words, these characteristics make it possible to distinguish general farming strategies at a regional level, but describing the differences of socio-economic characteristics between these strategies is difficult. This is in line with the statement of Vanclay et al. (2006) that types always overlap because the vast diversity of farm(er)s.

Farmers' willingness is assumed to have a major influence on land-use decisions and strategies (Fairweather and Keating, 1994; Willock et al., 1999a; Busck, 2002; Sharpley and Vass, 2006). However, the data showed exceptions. For example, although some agents were not supposed to diversify their farming practices based on their views, they did it in reality. This supports the claim of Burton and Wilson (2006) that farmers have different identities, depending on the circumstances when they take their decisions. Therefore, typologies do not represent reality perfectly, however, they are relevant tools whose use can facilitate our understanding of land-use dynamics (McKinney, 1950; Jollivet, 1965; Perrot and Landais, 1993b; Fish et al., 2003; Vanclay et al., 2006).

The method presented in this chapter depends on the amount and quality of the data. Thus, it requires a set of common variables through which different kinds of data can be linked. In addition, the information that farmers supply to registration systems might not always match with the real data (van der Ploeg, 2003). Related to this, a sample survey that tries to cover a whole region does not necessarily represent the entire population, leading to a mismatch between the sample survey and the statistical data used for allocation/classification.

Nevertheless, the agent typology formulated for the study area included many of the interactions that have been described in literature between farmers' views, farm(er) characteristics and current rural processes such as diversification of farm practices and farm expansion (e.g. Kelly and Ilbery, 1995; Austin et al., 1996; Willock et al., 1999a;

Knickel and Renting, 2000; Wilson and Hart, 2000; Ondersteijn et al., 2003; Knowler and Bradshaw, 2007; Jongeneel et al., 2008). Moreover, most of agent types defined in this research are related to one or to the combination of some of the identities that currently define European farmers (Burton and Wilson, 2006). All this suggests that the agent typology presented in this chapter has been able to capture the diversity of land-use decisions and strategies occurring in rural regions.

The analyses of the case study also confirm previous studies that showed that spatial location of a farm can influence land-use decisions and therefore farming strategies (Bryant and Johnston, 1992; Luttik and van der Ploeg, 2004; Jongeneel et al., 2008). These results also showed that the spatial distribution of such decisions and strategies are not randomly distributed throughout the landscape, which is in accordance with the findings of Köbrich et al. (2003). By defining agent typology and linking it with the landscape, the approach proposed in this chapter allows us to link agents' decisions to their environment, which is one of the key aspects of ABM (Balmann, 2000; Parker and Berger, 2002; Evans and Kelley, 2004). The empirical definition of an agent typology differs with the agent definition of most ABM that assume more "stereotype" agents with very different characteristics and decisions. In fact, the results suggest that defining "stereotype" agents may oversimplify the real diversity in decision-making, restricting their implementation to more theoretical problems.

According to Geertman and Stillwell (2003), Uran and Janssen (2003) and McIntosh et al. (2007), the lack of clarity and flexibility represents a barrier to implement land-use models and decisions support-systems in planning and policy-making processes. Because of its clarity and flexibility, the approach described in this chapter moves thus towards a better adoption of ABM in such processes. The flexibility of this approach makes it also suitable to be used in different rural regions, where farming systems and rural dynamics might be different.

In conclusion, the method described in this chapter is a simple and straightforward approach that combines different empirical methods to built agents-based models. This combination, together with the spatial definition of different agent types, allows us to parameterise, allocate and validate different agent types in an entire region. This empirical method is a step forward to include the diversity of land-use decisions and strategies in ABM at a regional level, as well as the spatial dimension where these decisions take place.

Chapter 3

Modelling framework

Abstract
LUCC is a complex process that includes actors and factors at different social and spatial levels. A common approach to analyse and simulate LUCC as the result of individual decisions is agent-based modelling (ABM). However, ABM is often applied to simulate processes at local levels, while its application to regional studies is limited. This chapter describes first an actor-based approach for ABM to analyse and explore regional LUCC processes. Second, the approach is implemented in an agent-based modelling framework by combining different concepts including agent typologies, farm trajectories and probabilistic decision-making processes. Finally, the framework is illustrated through a case study in the Netherlands, where processes of farm cessation, farm expansion and farm diversification are shaping the structure of the landscape. The framework is a generic, straightforward approach to analyse and explore regional LUCC with an explicit link to empirical approaches for parameterisation of ABM.

Based on: Valbuena D, Verburg PH, Bregt AK, Ligtenberg A. 2010. An agent-based approach to model land-use change at a regional scale. *Landscape Ecology*. 25(2):185-199.

1 INTRODUCTION

Land-use/cover change (LUCC) is the result of the interaction between humans and their environment. At the same time, LUCC influences both human and natural systems at different temporal and spatial levels (Vitousek et al., 1997; Foley et al., 2005; Turner et al., 2007). To understand these interactions, research should include not only the patterns and processes that link human-environmental systems and the feedbacks between them, but also the feedbacks between different organisational levels that influence the human-environmental interactions (O'Sullivan et al., 2006; Liu et al., 2007). In the case of LUCC in rural regions, these processes consist of actions and interactions of different actors operating at different levels who are continuously changing the structure and composition of the landscape. These actors include farmers, nature conservation organisations, urban developers and policy makers among others.

LUCC in a farm is determined by the use that people make of land, in particular of their own fields (Rindfuss et al., 2004). Farmers' decisions on how to use their land are complex as they are influenced by farm and regional factors (Siebert et al., 2006; Beratan, 2007). Farm factors include those personal, socio-economic and biophysical factors inherent to the farmer and to the farming system. In particular, existence of a successor, type of farm, amount of land and environmental constraints and possibilities are likely to influence land-use decisions (Gasson, 1973; Ilbery, 1978; Willock et al., 1999a; Gorton et al., 2008). Regional factors relate to the biophysical and socio-economic context. They include climate, the market, access to technology and policies. While farm factors determine whether the agent is willing and able to take certain decisions (Siebert et al., 2006), regional factors regulate or influence the range of farmers' options by modifying these willingness and ability (Lambin et al., 2001; Lambin and Geist, 2003).

Regional LUCC processes are often determined by the cumulative effect of changes occurring in farms, as well as processes of urbanisation, nature protection and infrastructure development. Often in rural regions, changes in the agricultural sector strongly affect the LUCC given the large areas used for agricultural activities. The diversity of decision-making of individual farms in a region reflects a range of possible combinations of different farm and regional factors (Busck, 2002; Köbrich et al., 2003). While farm factors are related to the farmer and their farm, regional socio-economic factors are linked to institutions and social networks, which have a role outside the farm. Institutions include local and regional governments, agricultural associations and the market. These institutions can react to market changes and to changes at landscape and regional level by setting legislation or providing incentives (e.g. policies to protect cultural landscapes).

A common approach to simulate LUCC as a result of variations in individual decisions and actions is the use of agent-based modelling (ABM) (Parker et al., 2003; Matthews et al., 2007; Robinson et al., 2007; Parker et al., 2008). ABM makes the simulation of interactions between both human and natural systems possible by defining different decision-making units or agents. Agents can have different internal characteristics and strategies, and can interact with other agents and their environment (Bonabeau, 2002; Sawyer, 2003). Although, the use of ABM offers the potential for understanding and exploring LUCC processes (Parker et al., 2003; Matthews et al., 2007), their relevance to predict LUCC has been limited by the inherent complexity of the processes that they try to address and by high data requirements (Couclelis, 2002; Verburg, 2006). Because of this complexity, the data requirements and the diversity of farming systems within agricultural regions, ABM has mainly been implemented in simulating local level LUCC processes (e.g. Acosta-Michlik and Espaldon, 2008; Le et al., 2008). When modelling regional LUCC processes, models are normally parameterised with artificial data (e.g. Ligtenberg et al., 2004). In fact, this parameterisation allow the use of ABM as a computational laboratory to investigate system responses (Berger and Schreinemachers, 2006). The level of abstraction in these applications has restricted their use in planning and policy-making processes.

The objective of this chapter is to describe an agent-based framework to analyse and simulate regional LUCC, making best use of empirical data that may be collected at this extent. In the following section of the chapter, we describe an actor-based approach to represent individual decision-making and link it to regional LUCC changes. In the next section, we implement this approach in an agent-based framework, including a probabilistic approach that aims to represent part of the diversity of decision-making strategies at the farm level within rural regions. Next, this framework is applied to a case study in the Netherlands, where farm cessation, farm expansion and landscape conservation are shaping the structure and composition of the landscape. In the final section of this chapter, we discuss the advantages, challenges and limitations of this approach.

2 Actor-based approach

In this section, an actor-based approach that conceptualises the decision-making process of farmers and its interaction with farm and regional factors is described, followed by its implementation in an agent-based framework.

2.1 System description

When investigating a specific decision-making process (e.g. expansion of the farm), farm factors can be seen as those aspects related to the ability and the willingness of farmers to carry out certain actions related to that process (e.g. buy or sell land). Ability refers to conditioning factors of the farmer and farm such as age, family structure, labour, farm size, spatial location, soil characteristics and slope (Siebert et al., 2006). This ability defines the options farmers have at a certain period for a specific decision-making process, what Wilson (2007) refers as decision-making corridors (Figure 3.1). According to this author, decision-making corridors define the possibilities and constraints of farmers' decisions. Willingness relates to farmer's values and intentions (Siebert et al., 2006) and defines the preference of the farmer for choosing certain options. For instance, whether a farmer will participate in nature conservation programmes is largely dependent on whether the farmer thinks that nature is important (Chapter 2; Valbuena et al., 2008). Because values do not change very often (Rokeach, 1968; Grube et al., 1994), willingness is assumed to be relatively stable in time. However, large modifications in the system (e.g. bankruptcy or changes in farm ownership) can drastically change the trajectory of a farming system, what Wilson (2007) calls transitional ruptures (Figure 3.1, time step 3). For example, a farmer with a large farm has been growing for the last years, but after major problems (e.g. lack of successor or illness) s/he decides to sell gradually her/his land. Ability and willingness are interrelated. If farmers have the willingness to grow but they lack the ability to do so, such a growth is almost impossible. Still, farmers can modify their ability in order to fulfil their willingness (e.g. take out loans to intensify the production of the farm; see regional factors below).

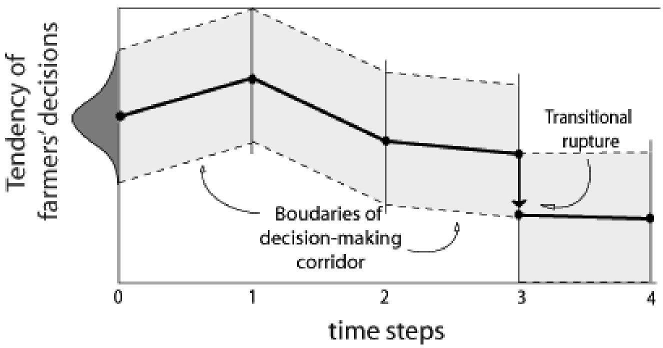


Figure 3.1. Representation of a decision-making corridor (after Wilson, 2007).

Farmers' decisions lead to certain actions, which can also affect their future options and decisions by changing their farm factors (Figure 3.2). This is an internal feedback mechanism that makes farmers' future options and decisions be dependent on previous actions (Figure 3.1, time step 0-2), to what Wilson (2007) calls system memory (i.e. path dependency). For example, a farmer decides to expand her/his farm by buying a new field; the size of his farm increases, modifying her/his ability and future options. The structure of a decision-making process linking options, decisions and actions is equivalent to the conceptualisation of decision-making processes described by Wooldridge and Jennings (1995) and the action-in-context framework (see de Groot, 1992; Huigen, 2004).

Factors that are external to the farm can also influence farmers' options and decisions. These are regional factors that include both compulsory and voluntary mechanism such as policies, loans, advice and demand for goods and services (Aarts and Woerkum, 2000). These factors reflect the interaction between farmers, social networks and institutions such as governmental organisations and the market (Figure 3.2). Although these institutions and factors occur at different organisational levels (e.g. from municipal governments to global market), this study only considers those that occur within the region as endogenous to the framework.

Interaction between farmers, institutions and social networks can be described by a number of different processes. First, institutions related to the development of rural regions can provide farmers with incentives that may influence farmers' ability, influencing their range of options and future decisions. Similarly, social networks (e.g. family and friends) can give advice to farmers, influencing their willingness for future decisions. For example, if a friend recommends a farmer to adopt a new technology, farmer's future decisions are likely to change (i.e. farmer's willingness). Second, to intervene or avoid certain actions of farmers, governments implement policies. Although these policies can influence directly the land-use/cover patterns of a region (e.g. the establishment of ecological networks to protect biodiversity through zoning legislation), they normally have an effect on farmers' ability by establishing certain policies such as subsidies for landscape conservation and manure policy. Finally, the demand for goods and services determines whether certain economic activity is a profitable option given the farm characteristics and its location. For instance, the demand for horse keeping is higher in rural regions located nearby urban areas than in other areas distant to cities.

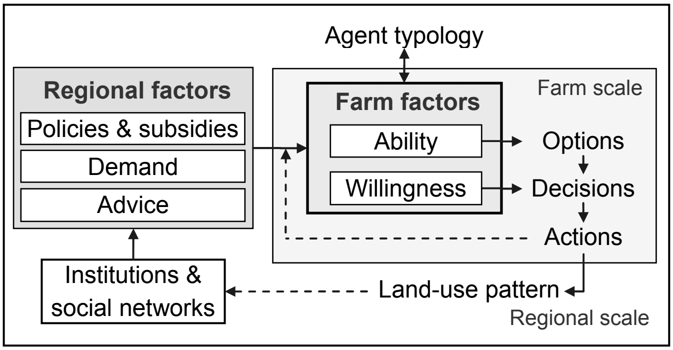


Figure 3.2. Interactions between individual farming systems and regional factors.

The interactions between farmers, institutions and social networks affect the environment (Figure 3.2). In a region, the cumulative result of farmers' actions can change the land-use pattern of rural areas. For example, to keep in business, many farmers in Europe have had to intensify their production activities affecting the connectivity and aesthetics of the landscape (Stoate et al., 2001). Changes in the composition and the structure of the land-use/cover patterns can affect in turn the functioning of the landscape and its capacity to provide goods and services, such as water storage, recreation and species habitat (de Groot, 2006; Willemen et al., 2008). Often, changes in the functioning of the landscape are the reasons why institutions try to influence farmers' options and decisions. For example, the high concentrations of nitrogen in water systems due to agricultural practices induced the adoption of a European Nitrates Directive in the early 90's, affecting many livestock farming systems (Petersen et al., 2007).

2.2 Model Implementation

For the implementation of the actor-based approach of Figure 3.2, a parameterisation of the ABM should be possible based on empirical data. To achieve such an implementation, an agent-based framework consisting of four steps is proposed:

- Simplify the diversity of farmers' decision-making by defining an agent typology;
- Represent agents' decision-making, including the influence of farm factors;
- Define the interaction between regional and farm factors; and
- Make a landscape representation in order to characterise the environment and to link it with agents' decisions and actions.

Agent typology

An agent typology is used to simplify the diversity of farmers' decision-making (Chapter 2; Valbuena et al., 2008). The definition of a typology based on agents' willingness and/or ability partly determines the direction and the boundaries of the decision-making corridor of the agent types for a specific decision-making process. This decision-making corridor represents both the options and decisions of each agent type for that specific decision-making process (Figure 3.1). Although agents of the same agent type share a similar willingness, differences in their ability (e.g. socio-economic conditions and different agent characteristics) may result in a large variability in decision-making. For example, two agents who have the willingness to diversify their farm practices into rural tourism can own farms with different sizes. This difference in farm size—or in labour, economic resources, family structure, age or location—affects whether they can increase their production scale in the coming years. The many different combinations between agents' willingness and ability explain why agents who belong to different agent types may take similar decisions or the other way around; agents who belong to the same agent type may take different decisions.

Decision-making and farm factors

Decision-making is specified for each decision-making process accounted for in the model. These processes can include either discrete decisions (e.g. stop or continue farming) or choices on a continuous scale (e.g. buy certain amount of hectares of land). Each of these processes consists of a set of options, which depends on the studied process and the level of detail of the analysis. To illustrate this representation of decision-making, we use a discrete process of farm expansion, which can be divided into three different and mutually exclusive options: buy, keep and sell land (Figure 3.3.A). To represent the diversity in decision-making of agents within an agent type, a probability is assigned to each option. When the probabilities of the different options are represented on a cumulative scale (Fig. 3A) the thresholds between the different options represent the cumulative probability of the different decisions. The values of these thresholds can be determined based on either expert knowledge, or be based on frequencies of decisions within the agent type population derived from observations of previous decisions or questionnaires. In Figure

3.3.A, the cumulative probability is represented for the options of the process of farm expansion. The thresholds between the options are: 0.1 for sell-keep and 0.7 for keep-buy. This means that only 10% the population of this agent type sold land, 60% kept the same amount and 30% bought land in the dataset that was used to parameterise this function.

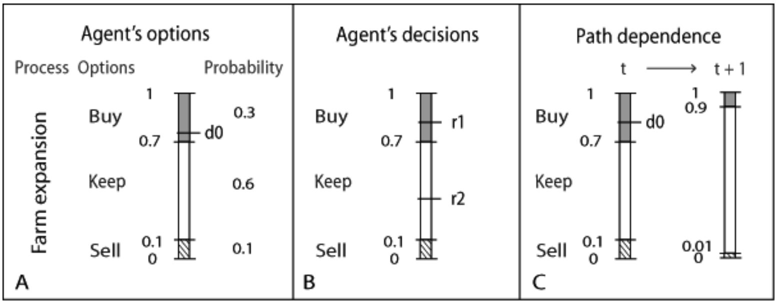


Figure 3.3. Representation of the decision-making process of farm expansion and agents' options (A), agents' decisions based on two different random numbers: r1 and r2 (B) and path dependence taking into account two iterations: t and t + 1 (C).

For each time-step and each agent, a decision is determined by drawing a random number (d0, Figure 3.3.A). Different probability distributions (e.g. uniform and log-normal) can be used to draw these random numbers. The probability distribution is determined based on the characteristics of the decision-making process and the information in the empirical data available to represent this process. Depending on the values of the thresholds between options, different random numbers may lead to different decisions. For example in Figure 3.3.B, if the random number is r1, the agent would buy land, whereas if the random number is r2, s/he would keep the same amount of land. In other words, agents' decision-making is based on a probabilistic approach. This representation of agents' decision-making is similar to those formalisations mentioned by Benenson and Torrens (2004). These authors describe different implementations to represent agents with bounded rationality, which means that agents have limited knowledge and ability (Simon, 1955). These implementations are seen as probabilistic choices between a range of options such as buy or sell land (Benenson and Torrens, 2004). Agents' decisions can lead to actions that take place either at the same time step (e.g. cut a tree) or in the near future (e.g. start saving money to buy a field). Since future options, decisions and actions are dependent on previous ones (i.e. path dependence), the likelihood that an agent would decide for a specific option is influenced by her/his previous decisions and actions. To represent this path dependency of decision-making, the values of the thresholds between different options are affected by the previous decision. In Figure 3.3.C, her/his decision and action to buy land (t) partly limit the likelihood that the agent will buy (0.1) or sell (0.01) land in the next iteration (t + 1), being more likely to keep the same amount of land (0.89). This dependency of previous and subsequent probabilities can be considered as a Markov process, in which the next step of a stochastic process is determined by the previous one (Benenson and Torrens, 2004).

Besides path-dependence in decision-making, other farm factors and processes also influence agent's decision-making. First, to include the diversity of decision-making between agent types, agents of two different types have different likelihood to decide for a specific option. For example, if an agent belongs to an expansionist type (type X, Figure 3.4.A), the likelihood that this agent buys land is higher than that of an agent who belongs to a non-expansionist type (type Y). Second, to represent transitional ruptures of agents' decision-making corridors, values of the thresholds between different options can be modified, changing the farming strategy of the agent. In Figure 3.4.B, an agent who had expanded her/his farm (t0) decided to stop farming in the coming years drastically affecting her/his future options and decisions of buying or selling land (t1). Finally, the influence of internal feedbacks can be represented in a similar way to that of the regional factors (see below).

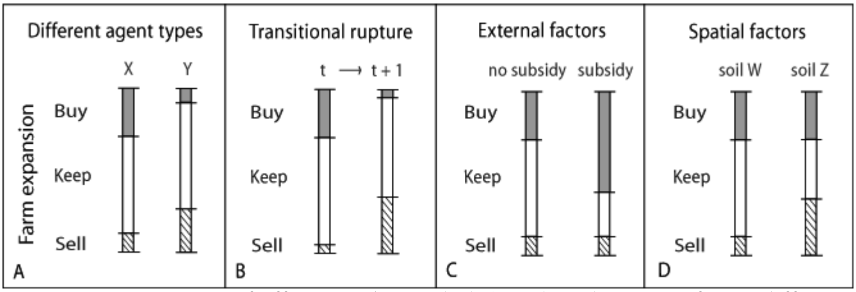


Figure 3.4. Representation of effect on the probability distributions of: (A) different agent types; (B) transitional rupture; (C) regional factors; and (D) spatial factors.

Regional factors

The effect of regional factors on agent's farm factors, and thereby on her/his options and decisions can be also represented by changing the likelihood for certain options. For example, the government adopts a policy that encourages farmers to expand their farms by purchasing more land, which influences agent's options and decisions (Figure 3.4.C). To link agents' actions and regional factors, indicators are used. Indicators help to measure changes in the agent population and in the land-use patterns of the region. When these indicators reach certain thresholds, institutions will respond by modifying the regional factors, and therefore, agents' options and decisions. For example, if connectivity of nature areas decreases drastically, policy-makers can implement restrictions on the removal of landscape elements, limiting agents' options.

Landscape representation

Landscapes can be represented by different indicators, such as land-use patterns, farm size and agent density. This representation depends on both the objective of the study, which includes the type of processes to be taken into account, and the availability of spatial data.

The representation of the landscape by a number of variables is also used as a spatial factor that can describe agents' ability. For agricultural practices, these variables may include the suitability of the land for specific purposes, which may affect the probability distribution of a decision based on soil quality (Figure 3.4.D). To calculate these effects, spatial analyses on landscape characteristics and cadastral data can be carried out. Based on these data it possible to analyse on which soils it is more common to cultivate a certain crop. Thus, based on the specific field conditions the same type of agent is likely to take different decisions in different fields.

3 MODEL APPLICATION

The functioning of some key characteristics of the framework is illustrated in the Achterhoek. The Achterhoek is a rural region in the eastern part of the Netherlands. This region covers an area of 60.650 ha. Dairy production is the dominant agricultural sector in the region. Currently, processes of farm cessation, farm expansion and diversification of farm practiceses are influencing the region (see section 2.2, Chapter 1).

3.1 Data parameterisation

To built an agent typology and define the ability and willingness of the farmers, this study makes use of a sample survey of 333 farmers carried out in winter 2004. The survey was originally conducted to explore the factors that determine the diversification of farm practices including farmers' views (positive, neutral and negative) and structural variables such as the existence of a successor, production scale, degree specialisation of the farm and past land-use changes (Jongeneel et al., 2005; Jongeneel et al., 2008). As there is no database available that contains information on the willingness and ability of the whole population, census data for two different periods (FADN, 2001 and 2005) were used to describe part of the ability of the whole population and to determine previous land-use decisions in farm expansion. Additional socio-economic and spatial data of the region (e.g. soil characteristics, cadastral data and landscape structure, including the presence of linear landscape elements) were used to establish the ownership of the fields and other spatial characteristics of the fields. The model was built in NetLogo 4.0 (http://ccl.northwestern.edu/netlogo/).

Agent typology

The definition of the agent typology was based on both the willingness and ability of farmers in terms of farm expansion and diversification of farm practices. Specific attention was paid to differences in willingness to protect landscape elements such as hedgerows and tree lines. Willingness was defined by: whether diversification of farm practices is seen as an economic alternative; whether farmers would expand their farms; and, whether they would participate in programmes for nature and landscape conservation practices. Ability was based on whether farming represents a core business or not (farmers vs. hobby farmers). Based on this combination of farmers' willingness and ability, five different agent types were defined for the region: hobby, conventional, diversifier, expansionist-conventional and expansionist-diversifier (Chapter 2; Valbuena et al., 2008). 'Hobby' includes agents whose income does not depend on farming activities and who do not own enough land or have no willingness to participate in programmes for nature and landscape conservation. 'Conventional' includes agents who prefer to keep farming, but who do not want to expand their farm. Although these agents prefer not to participate in conservation programmes, some of them may still participate because farming does not produce enough income. 'Diversifier' includes agents who instead of expanding their farm prefer to diversify their income by, for example, participating in programmes to manage nature and the landscape. 'Expansionist-conventional' includes agents who prefer to keep farming by increasing the size of their farm. Finally, 'expansionist-diversifier' represents agents who would like to do both: to expand and to diversify their farm practices (table 2.1, Chapter 2).

Decision-making and farm factors
Each decision-making process was represented as a range of probabilities between 0 and 1. The probability of selecting a certain option for each process was estimated by using the proportion of farmers of the sample survey who belonged to the same agent type and who took/would take similar decisions. For instance, around 34% of the hobby agents would stop farming under the existing circumstances, whereas only 4% of the expansionist-diversifier agents would stop farming. Therefore, the probability to stop farming was much higher for the hobby (0.34) than for the expansionist-diversifier type (0.04). The initial conditions for each of the selected process were calculated based on a random number (uniform distribution) and historical data.

Table 3.1. Overview of simulated processes and variables used to define agents' options and decisions and select the fields.

Process	Options	Periodicity	Variables: agent-level	Variables: field-level
Farm cessation	Stop Heritage	Once in the agent's life	Agent type Age	None
Farm expansion	Sell Stable Buy	Each time step	Agent type Previous actions* Farm size & policies	Distance to the agent
Protection of landscape elements	Cut Keep Plant	Each time step	Agent type Previous actions Farm size & policies	Soil type Surrounding linear landscape elements

*Including their decisions related to farm cessation

The set of options and variables affecting agents' decisions vary for each selected process (see Table 3.1). For farm cessation, agents can decide whether they continue or stop farming. If an agent wants to continue, her/his strategy and the one of the successor will not drastically change. The decision to stop farming is possible when agent is 50 years old. However, if an agent decides to stop farming, changes in the agent type (i.e. transitional ruptures) and in decision-making are expected (i.e. the likelihood to sell land is higher than for an agent that has decided to keep farming).

For farm expansion, agents can buy or sell land, or keep the current position. The farm factors influencing the probability to decide for any of these options were agent type and previous decisions (i.e. agent memory). Specifically, the influence of previous decisions was calculated by comparing the farm size of the census data of the whole population of the region between 2001 and 2005. In this way, the more land an agent bought in the last five years, the less likely s/he will buy land. Related to this, if an agent buys a field, s/he would not be able to sell land after five years. The action of buying land is restricted by land availability in the neighbourhood. Thus, if there is a field or a farm available, the closest buyer can buy it. The selection of which field an agent will sell depends on the distance of the field to the owner. This relation was estimated based on a spatial analysis of the cadastral data. If an agent decides to stop farming the whole probability distribution is modified by calculating again the initial condition and by establishing the boundaries of her/his new agent type. Also, this agent can only sell or keep her/his land.

For the protection of linear landscape elements, agents can plant new elements, and then, remove or keep existing elements. The farm factors influencing the probability to decide for any of the options were agent type, previous decisions and availability of land. If an agent plants a new element, the whole probability distribution changes and the agent will have the option of cutting the landscape element only after some period of time (see below). Agents with larger farms have more possibilities to plant new landscape elements. To decide in which field a landscape element will be planted depends on the type of soil of each field (e.g. peat soils were more likely to have landscape elements than sandy soils) and the existence of landscape elements around that field. These relations were also quantified based on additional spatial analyses of the current landscape structure in the region.

Regional factors

The interaction between farm and regional factors was defined by two indicators: the percentage of the area managed by agents with small-scale production (AREA) and the density of linear landscape elements (ELEMENT). Each indicator is related to a specific process. AREA was defined as indicator of farm expansion. Small-scale production was defined as those farms with less than 50 Dutch Standard Units (dsu; in 2005 a dsu was equal to 1400 Euros). When AREA drops below the 25% of the total agricultural area, a policy is adopted. This policy creates incentives that promote agents to keep their land by changing the probability of selling fields. It was assumed that this policy did not influence the process of farm cessation.

ELEMENT was defined as indicator of the protection of linear landscape elements. When a policy to protect these elements is adopted, agents can participate by planting new linear landscape elements, affecting the density of these elements in the landscape. The rate of adoption of this policy is influenced by the probability of an agent to belong to an agricultural association for nature and landscape management. For example, diversifiers are more likely to be part of one of these associations, and more likely to adopt this policy. To adopt again the policy, agents have to wait for two years. They also have to adopt the policy for at least 6 years.

Landscape representation

Based on the selected indicators, the landscape was represented by the area managed by agents with small production, and by the density of linear landscape elements per hectare. Urban areas, bodies of water and nature areas were represented as static land-use types. Based on cadastral data, agents owned a farm that was formed by one or several fields. These fields could be clustered or spread over the region. Each field could be formed by one or several pixels. This means, that each pixel belonged to a certain field, a certain farm and a certain agent. For each field, and therefore each pixel, the size, the soil type, the distance to the owner and the density of linear landscape elements were determined.

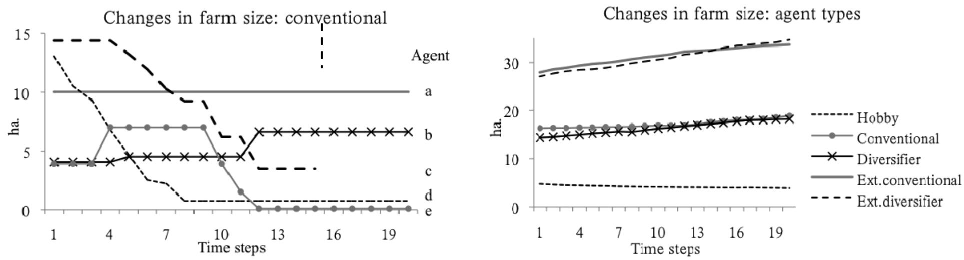
3.2 Simulation

To illustrate the functioning of the application of the modelling framework, the model was run for three different sets of parameters for a period of 20 years. First, the model was run to illustrate the decision-making process and the influence of internal feedbacks on the trajectory of individual agents and on the regional population. Second, the model was run including regional factors, specifically the effect of these factors on the agent population. Third, the model was run to illustrate the potential effect of regional factors on the structure of the landscape. In addition, for this parameter setting the model was run 100 times, each time with a different random seed. These additional runs illustrate how to calculate and visualise the uncertainty in a decision-making process in which each decision was specified through probability distributions.

Decision-making and farm factors

Figure 3.5.A shows the different simulated trajectories of a number of individual agents of the agent type conventional. Most agents have a clear tendency: to grow (agent b), to keep the same amount of land (agent a) or to decrease their farm size (agent d). Other agents, however, drastically changed the direction of their trajectory caused by a transitional rupture (agent e), which in this case was the result of the decision of the agent to stop farming in the following years. Related to this, before agents stopped farming, a decrease in their farm size was often seen (agent c). Although similar trajectories were present in all the agent types, the general tendencies for each agent type differed (Figure 3.5.B). While the average farm size of the agent type hobby decreased almost 1ha, the average size of the other agent types increased. Yet, such an increase was higher for expansionist types (approx 6ha) than for non-expansionist types (approx 3.5ha).

Changes in the average farm size between agent types are also related to other changes in the agent population of the simulated results (Table 3.2). Although there was a decrease in the agent population of almost 16% due to farm cessation, most of the agents who stopped farming belonged to the hobby, conventional and diversifier agent types. In a similar way, around 17% of the agents who belonged to these agent types decreased the size of their farms. Still, around 23% of those agents who belonged to agent type conventional and diversifier bought land. Finally, most of the expansionist bought land and few of them sold their land or stopped farming. These results show that the agent type defines the different options and trajectories that an agent can follow, but still keeping the diversity of agent decisions within each of these agent types.



A B

Figure 3.5. Different trajectories of the simulated changes in farm size for the agent type conventional (A), and the average farm size of each agent type based on the entire agent population (B).

Table 3.2. Summary of the simulated results of changes in farm size per agent type, including the initial number of agent per agent type, the number of agents after the simulation, the proportion of farmers who stopped farming, who increased their farm size and who decreased it.

Agent type	Initial number	Final number	Stop farming %	Increase land %	Decrease land %
Hobby	1036	816	21.2	19.7	12.9
Conventional	566	442	21.9	27.0	20.3
Diversifier	294	240	18.4	27.6	22.4
Exp. conventional	715	679	5.0	46.0	1.3
Exp. diversifier	130	125	3.8	52.3	0.0
Total	2741	2302	16.0	30.5	11.8

Exp. = Expansionist

Regional factors

The adoption of the policy that promoted agents to keep their land (indicator AREA) had a different impact on the options and decisions of the different agent types (Table 3.3). Specifically, the likelihood that many non-expansionist agents sold their land was lower.

Thus, the adoption of this policy reduced the percentage of these agents selling their land. However, as this policy did not influence agents' decisions related to the process of farm cessation, the percentage of agents per agent type who stopped farming was similar with or without the adoption of the policy. As many agents with small-scale production stopped farming, the area they managed still dropped to 18% of the total area. The adoption of a policy to protect the linear landscape elements (indicator ELEMENT) also showed differences between agent types (Figure 3.6). While around 35% of the diversifier and expansionist-diversifier agents participated in the policy, only around 20% of the other agents participated.

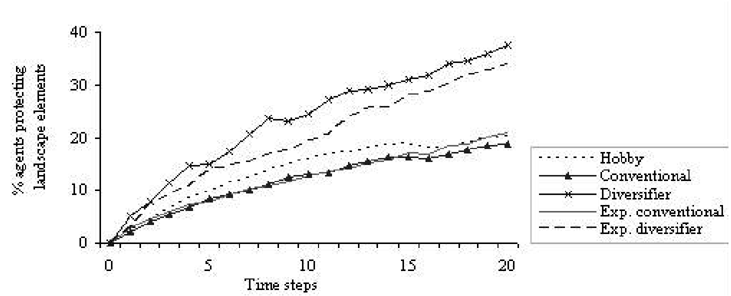


Figure 3.6. Percentage of agents per agent type who participate in the policy to protect linear landscape elements.

The spatial distribution of each agent type is not homogeneous throughout the region, and therefore, the adoption of the policy is also unevenly distributed (Figure 3.7.A). This link between individual decisions and policy adoption facilitates the spatial analysis and exploration of the potential influence of policies on regional changes. For example, with these results it is possible to have an overview on the potential number of participants in a specific policy, as well as the potential changes in the structure of the landscape that this policy might cause (Figure 3.8).

Table 3.3. Summary of the simulated results of changes in farm size per agent type for the small-scale policy scenario, including the initial number of agents per agent type, the number of agents after the simulation, the proportion of farmers who stopped farming, who increased their farm size and who decreased it.

Agent type	Initial number	Final number	Stop farming %	Increase land %	Decrease land %
Hobby	1036	789	23.8	16.5	4.2
Conventional	566	448	20.8	24.9	6.4
Diversifier	294	227	22.8	29.6	4.8
Exp. conventional	715	701	2.0	44.5	0.1
Exp. diversifier	130	125	3.8	56.2	0.0
Total	2741	2290	16.5	28.8	3.5

Exp. = Expansionist

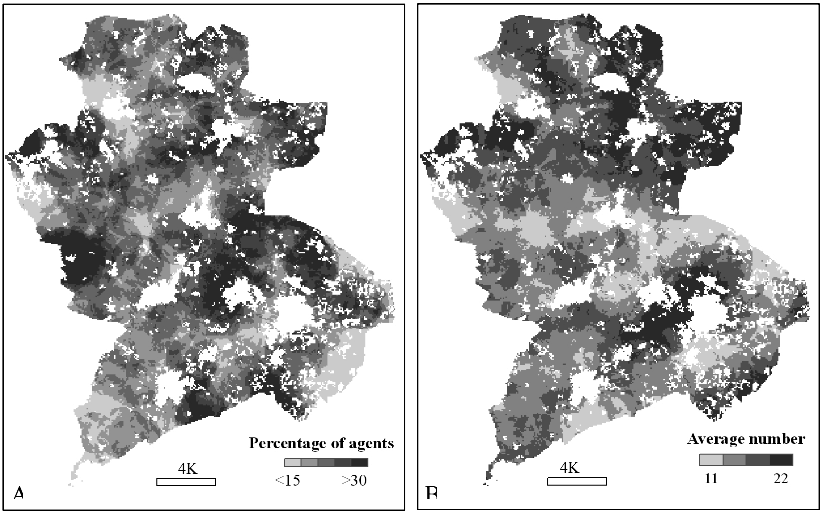


Figure 3.7. Agents' participation in the policy to protect linear landscape elements. % of agents who participated in the policy by running the model once (A). Average number of times that agents participated in the policy by running the model 100 times (B).

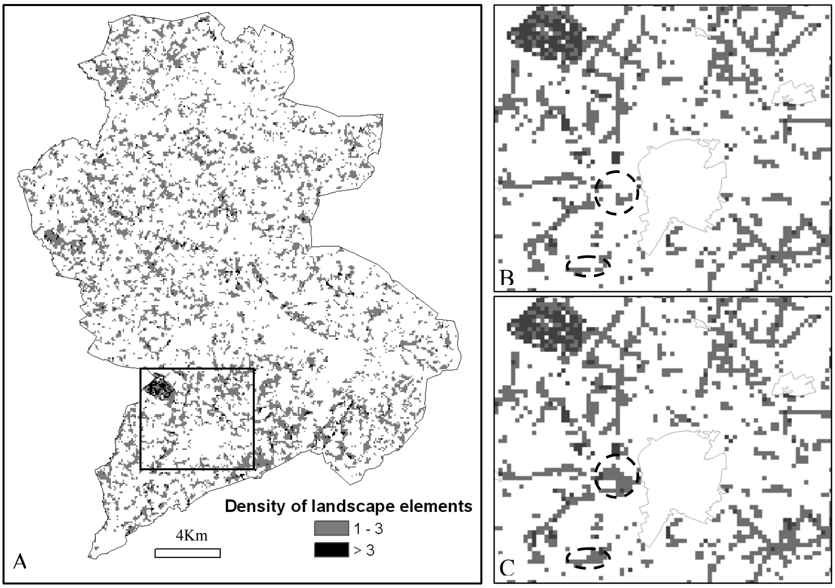


Figure 3.8. Percentage of landscape elements per hectare: base map year 2005 (A and B); and simulated map after 20 years (C).

The results of running the model 100 times with different random seeds showed a high variability in the results (Figure 3.7.B). While the number of agents adopting the policy was relatively similar between runs (average 440, standard deviation 45), the group of agents adopting the policy changed, as well as the spatial distribution of the adoption of the policy. This illustrates the uncertainty attached to the probabilistic approach, the overlap of decision-making between the different agent types and the complexity of human-environmental systems.

4 DISCUSSION AND CONCLUSIONS

The actor-based approach presented and implemented in this chapter addressed two main challenges in the study of regional LUCC. The first challenge relates to including the diversity of decision-making in regional modelling. In ABM developed for local case studies, all the different decision-making strategies can be described and quantified in detail by using individual questionnaires or participatory calibration (Bousquet and Le Page, 2004; Janssen and Ostrom, 2006; Robinson et al., 2007). To gather these data of the population of an entire region is less feasible. This relates to the common practice of overlooking the diversity of decision-making strategies in regional land-use models (e.g. Clarke et al., 1997; Pijanowski et al., 2002; Overmars et al., 2007). In the agent-based framework proposed in this chapter, the combination of individual agents, an agent typology and a probabilistic decision-making approach allow us to simplify and include the inherent variability of the population and decision-making in rural regions. Further, the proposed framework makes a relatively simple parameterisation of the model possible based on data that are available or can be collected in rural regions.

The second challenge relates to the empirical parameterisation of ABM, specifically models with a regional extent. In the application of the agent-based framework, the parameterisation with empirical data of both the agents' decision-making process and the influence of farm and regional factors on agents' options and decisions was achieved by linking different concepts and different datasets. Spatial data, including cadastral data, were used to represent and understand general land-use patterns at field level. The analysis of survey data was used to develop an agent typology that accounted for differences in decision-making. Census data of the whole population were used to identify and quantify internal feedbacks. The use of different datasets relates to the statement of Robinson et al. (2007) that using different collection methods is the best way to parameterised empirically an ABM.

The implementation and application of this modelling framework have several advantages. One of the main advantages is that by merging general concepts and approaches such as farmers willingness and ability (Siebert et al., 2006), decision-making corridors (Wilson, 2007), agent typologies (Chapter 2; Valbuena et al., 2008) and probabilistic decision-making, this is a flexible and generic framework to implement and apply a regional ABM for land-use research. In fact, this flexibility allows us to apply this framework to different LUCC processes and different regions. In regional studies the framework allows, by defining and using different decision-making strategies, to include the diversity of farming systems. Such a diversity is an important factor explaining the interaction between farmers' decision-making and the landscape structure of rural regions (Thenail and Baudry, 2004). Further, a generic framework facilitates the comparison not only between conceptual approaches, but also between ABM applications (e.g. Grimm et al., 2006; Parker et al., 2008). Both generalisation and comparison have been identified as key topics in ABM for land-use research (Rindfuss et al., 2008). Another advantage is that the probabilistic approach used in this framework facilitates the quantification and visualisation of the uncertainty of the modelling process. This is in line with the statement of several authors that uncertainty needs to be quantified, represented and included in the outputs of ABM (Parker et al., 2003; Messina et al., 2008), and even in policy-making processes (Bradshaw and Borchers, 2000). Finally, by including the diversity between and within agent types, this modelling framework includes part of the diversity of decision-making processes, which is an essential characteristic of the human-environmental system (Köbrich et al., 2003; Matthews et al., 2007).

The application of the modelling framework reveals some challenges and limitations. A challenge of the application of this framework, but also of ABM in general, is the validation of the model (Crooks et al., 2008; Messina et al., 2008). Although sensitivity analyses, the visualisation of uncertainty, and multi-temporal surveys and census provide relevant datasets to verify the simulated processes (Bousquet and Le Page, 2004; Crooks et al., 2008), the availability of detailed data on the willingness and ability of the whole population is often lacking or restricted. Still, statistical methods to control further the bias, noise and collinearity in such probabilistic models can be also carried out (Santner et al., 2003). These methods can be used to verify the internal properties of the simulation processes itself. Also, if consistent high-resolution data for two years are available, validation may be possible by comparing the simulated results to past or current land-use patterns (Brown et al., 2005; Pontius et al., 2008). Another challenge is linked to the interactions between agents and their social networks. Although decision-making of other actors such as policy makers and nature conservationists can also be represented by using the modelling framework applied in this chapter, to quantify and to represent spatially these socio-economic interactions is challenging. Yet, the use of external feedbacks in this actor-based approach is a first step to include empirically these interactions in regional ABM. Finally, agricultural practices in this chapter were represented by the main agricultural activity, disregarding the diversity of these practices in the farm and in the region (e.g. different livestock systems and crop rotations). Agricultural practices are closely related to the structure and dynamics of landscapes in rural regions and the agent type itself (Thenail and Baudry, 2004). To include this diversity of agricultural practices in the application of the modelling framework described in this chapter would help us to analyse and explore better the interaction between farmers' decisions and the landscape patterns in rural regions.

The main limitation of this probabilistic approach is the randomness attached to it. As ABM in land-use research is developed to deal with complex human-environmental systems, it is unlikely to gather all the required data to parameterise the model. Related to this, we need to understand the meaning of those probabilities and to link them to real processes (Batty and Torrens, 2001). In this specific application, several assumptions were made including the initial conditions of each agent, the stability of the probabilities of the agent types in time and the quantification of the link between past and future decisions. This limitation relates to the statement of several authors that ABM has a limited predictive capacity and that their use relies on their capacity to analyse and explore the dynamics of such complex systems (Batty and Torrens, 2001; Couclelis, 2002; Matthews et al., 2007; Zellner, 2008). Still, as mentioned by Matthews et al. (2007), this level of uncertainty can be decreased by including the knowledge of different stakeholders in the construction of ABM.

The agent-based framework described and implemented in this chapter represents a step towards the development of empirical regional models that take explicitly into account the diversity of decision-making strategies. To achieve this, we combined existent concepts and approaches to create a generic approach in regional ABM. By being flexible and generic, this framework can be applied to different LUCC processes and different regions where the diversity of individual decision-making is a driver of LUCC processes.

Chapter 4

Policy changes and farmers' decisions

Abstract

The development of rural regions is a result of multiple (spatial) interactions between socio-economic and biophysical processes. These processes largely differ between European rural regions as result of the interaction of endogenous and exogenous processes of a region. In particular, the diversity of farmers' decision-making in rural regions is an important process that determines how farming responds to exogenous processes. This response can affect the use and the structure of the landscape. The aim of this chapter is to explore how future responses of farmers' decision-making to endogenous and exogenous processes can affect the regional landscape structure. This is achieved by implementing different future scenarios in an agent-based modelling framework for a rural region in the Netherlands. The results show how the response of farming to global or regional processes either polarise or interconnect agriculture and nature in the rural region. The results also demonstrate how different types of decision-making can influence passively or actively the structure of the landscape. The added value of including the diversity of farmers' decision-making in regional land-use research is discussed.

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1 INTRODUCTION

The social, economic and spatial dynamics of European rural regions are dominantly influenced by the dynamics of the agricultural sector (European Commission, 2006). A rural region is defined as a territorial unit where small urban centres are surrounded by large low-dense populated areas of open space and where a regional economy takes place (Terluin, 2003). Within European rural regions, changes in agriculture have been taken place including intensification/extensification of farming, diversification of farm practices, urbanisation, land abandonment and farm expansion (Meeus et al., 1990; Marsden, 1999; MacDonald et al., 2000; Stoate et al., 2001; Antrop, 2004).

Changes in agriculture result in processes of land-use/cover change (LUCC) (Mander and Jongman, 1998; Henle et al., 2008). In the last decades, agricultural changes and LUCC processes have caused several modifications in the landscape structure of European rural regions (Vos and Meekes, 1999). Intensification of farming has caused an increase in the field size and drainage of wetlands, whereas the number of hedgerows, tree lines, ditches and traditional farmhouses has decreased. Extensification and land abandonment in Europe have generated the decline of cultural landscape elements such as farmhouses, old bridges and paths. Also, the lack of management has allowed scrub and woods encroachment into semi-natural landscapes. Urbanisation and infrastructure development have caused losses in habitat and landscape fragmentation. All these changes have affected the structure, identity and diversity of the landscape and often caused a loss of the historical and cultural character of European rural regions (Meeus et al., 1990; Baldock et al., 1996; Vos and Meekes, 1999; Poyatos et al., 2003; Antrop, 2004).

Changes in agriculture largely vary between European regions due to the interaction of processes and factors that occur at different organisational, spatial and temporal levels. These processes and factors can be categorised as endogenous and exogenous processes of a region (Bowler, 1999; Terluin, 2003). Endogenous processes are socio-economic and biophysical conditions of a specific region including population, farming, social institutions, local and regional governments, topography and water availability (van den Bor et al., 1997). Exogenous processes include those occurring at global and national levels, varying from changes in the global market to climate change, including global agreements such as the World Trade Organisation and policy frameworks such as the Common Agricultural Policy of the European Union (Olesen and Bindi, 2002; Wilson, 2007; Pollock et al., 2008). Often, endogenous processes determine how local communities, especially farmers, respond to the exogenous processes (van den Bor et al., 1997). The response of farmers in rural regions, however, is not homogenous and different decision-making strategies can be distinguished representing how farming has developed and can develop in a specific rural region (Bowler, 1992; Meert et al., 2005).

In regional land-use research, the spatial and temporal effects of changes in the endogenous and exogenous processes of a region on the landscape structure are often analysed and explored based on the aggregated interaction between social, economic and biophysical processes (e.g. Clarke et al., 1997; Verburg et al., 2002) and not on the interaction of the individuals and institutions involved in LUCC. Analysis of LUCC as the result of these aggregated interactions allow us to visualise and represent past, current and future LUCC patterns (Verburg, 2006). However, these analyses do not include the diversity of farmers' decision-making of a region. Looking only at the empirically estimated influence of these aggregated interactions does not allow us to understand and explore LUCC as a response of the decision-making of local communities to the exogenous processes of a rural region. The aim of this chapter is to analyse and explore how the response of the diversity of farmers' decision-making to exogenous processes can affect the landscape structure of a rural region. This chapter addresses this question by exploring how potential future changes in farm cessation, farm expansion and nature protection policies affect the landscape structure in a rural region in the Netherlands. An agent-based model (ABM) was used to account explicitly for the diversity of decision-making of the region. Scenarios were used in the modelling process to explore different potential changes in the endogenous and exogenous processes of the region.

2 METHODS

The study area is the Achterhoek. The Achterhoek is a rural region in the eastern part of the Netherlands. This region covers an area of 60.650 ha. Dairy production is the dominant agricultural sector in the region (see section 2.2, Chapter 1).

In this section we first explain the different steps we used to represent and simulate farmers' decision-making in an ABM. Next, different future scenarios for the study area are described.

2.1 Model application

To apply the modelling framework described in Chapter 3 (Valbuena et al., 2010), different data sources were used. Agents' willingness and ability were defined based on a survey of a sample of the farming population of the region (Jongeneel et al., 2005; Jongeneel et al., 2008). Agents' willingness was described as whether diversification of farm practices was seen as an economic alternative; whether farmers would expand their farms; and whether they would participate in programmes for nature and landscape conservation practices. Agents' ability was described as whether farming represents their main income (farmers vs. hobby farmers), age of the farm head, agribusiness type (i.e. dairy faming, intensive livestock farming, etc), farm size, likelihood of the existence of a successor and the location of the agent and the farm. Regional factors are described in the scenario description section.

For the agent typology, agents' willingness and ability were used to differentiate five different agent types (Chapter 2; Valbuena et al., 2008). (1) 'Hobby' includes agents whose income does not depend on farming activities and who do not own enough land or are unwilling to participate in programmes for nature and landscape conservation. (2) 'Conventional' includes agents who prefer to keep farming, but who do not want to expand their farm. Although these agents prefer not to participate in conservation programmes, some of them may still participate because farming does not produce enough income. (3) 'Diversifier' includes agents who instead of expanding their farm prefer to diversify their income by, for example, participating in programmes to manage nature and the landscape. (4) 'Expansionist-conventional' includes agents who prefer to keep farming by increasing the size of their farm. (5) 'Expansionist-diversifier' represents agents who would like to do both: to expand and to diversify their farm practices. The parameterisation of the agents' decision-making is explained in Appendix A.

Two spatial variables that are connected to farmers' decisions were selected in order to analyse the influence of such decisions on the landscape structure of the region. The first one is the proportion of nature in the area surrounding the location (radius 1 Km), which indicates the homogeneity of the landscape (e.g. agricultural or natural landscapes). Although, the development of nature might take some years after an agricultural field is abandoned, we included all abandoned fields as nature. The second variable is the density of surrounding landscape elements such as hedgerows and tree lines (radius 0.5 Km), which can be used to describe the scale of the landscape (e.g. small and large scale). The representation of the landscape based on its composition and structure is similar to the method described by Dijkstra et al. (2000). Based on the values of the two selected variables, six different landscape classes were distinguished (Table 4.1). The aim of distinguishing these different landscape classes was to visualise and analyse the combined results of changes in the proportion of nature areas and the density of landscape elements.

The validation of an ABM is a difficult task (Messina et al., 2008). By simulating human decisions, ABM deals with the complexity and uncertainty of human decision-making and of the socio-economic and biophysical systems where these decisions take place (Parker et al., 2003; Rand et al., 2003; Bousquet and Le Page, 2004; Brown et al., 2005). Due to this complexity and uncertainty, validation of individual decisions and interactions is troublesome. In this chapter, an expert validation was carried out to validate the plausibility of the simulated results. Unstructured interviews were carried out with five experts of the region who belonged to different local and regional organisations. Although the main aim was to validate the quantity and location of changes in the landscape structure of the region, their views on the assumptions for each scenario were also taken into account.

2.2 Scenario description

Scenarios are often used to cope with the uncertainty about future developments and events in the endogenous and exogenous processes of a region (Nakicenovic et al., 2000; Rounsevell et al., 2006; Verburg et al., 2006). Scenarios are tools that help us to evaluate current or future environmental problems and to assess the potential influence of alternative policies on solving these problems (Alcamo, 2001; Wilkinson and Eidinow, 2008). A series of studies have adapted the IPCC scenarios (Intergovernmental Panel on Climate Change; Nakicenovic et al., 2000) for the Netherlands (MNP and RIVM, 2004; de

Bont et al., 2005) and for specific regions within the country, including the study region (van der Kolk et al., 2007). This has been done to analyse the potential consequences of changes in the exogenous processes of a region (e.g. market liberalisation or development of regional markets) on the endogenous processes of specific Dutch rural areas. Based on the current trends and on the regionalised versions of the IPCC scenarios, three different scenarios were simulated for the case study.

Table 4.1. Classification table of the landscape classes of the region based on values of scale and openness of the landscape.

Landscape class	Description	Density nature areas	Length linear elements
1	Low density of nature areas + few landscape elements	< 5 %	< 30 m per ha
2	Low density of nature areas + landscape elements	< 5 %	> 30 m per ha
3	Medium density of nature areas + few landscape elements	5 - 20 %	< 30 m per ha
4	Medium density of nature areas + landscape elements	5 - 20 %	> 30 m per ha
5	High density of nature areas + few landscape elements	> 20 %	< 30 m per ha
6	High density of nature areas + landscape elements	> 20 %	> 30 m per ha

Trend scenario

This scenario represents a continuation of the current trends faced by the region. In the last decades, restrictions on milk production and manure application, and the establishment of subsidised programmes for nature and landscape protection have largely affected the rural dynamics not only in this study region, but also in most of the rural areas in the Netherlands and Europe (van Horne and Prins, 2002; Graveland et al., 2004; Oerlemans et al., 2004; Berkhout and Bruchem, 2005). In the region, between 1998 and 2005, the total number of farmers decreased about 27%, the production per hectare also decreased with approximately 26%, while the average farm size increased with 30% (Korevaar et al., 2008). As current trends are assumed in this scenario to remain constant in the coming years, it is expected that by 2020 the number of farms will drop. Most of the land available will be incorporated in other farms. Fields that become available for selling and that are located in the National Ecological Network (EHS) are converted to nature areas. The EHS is an ecological corridor designed to connect nature areas in the Netherlands. In recent years there is a low rate of agricultural land incorporated in the EHS (Geertsema et al., 2003; de Boer et al., 2008). Therefore, the development of the EHS is assumed to be a passive process that basically depends on the availability of land. In addition, as density of hedgerows and tree lines have not varied considerably in the last years (Koomen et al., 2007), it is assumed that farmers will neither plant nor cut these elements.

A1 scenario

This scenario represents a liberalised world, where individualisation, economic growth and new technologies are key drivers of the socio-economic development (MNP and RIVM, 2004). For the Dutch agriculture, this liberalisation represents the end of the milk quota and the price support measures and the income support policies that are part of the CAP. Further, it is assumed that few or no new policies related to environment, nature and animal care are adopted (de Bont et al., 2005). These changes in the exogenous processes and factors of the region will increase the likelihood that farmers stop farming. It is assumed that these changes would affect more farmers who own arable and dairy farms than mixed farms (de Bont et al., 2007). Although farmers would have a larger capacity to buy land than in the Trend scenario, this capacity would be larger for those farmers willing to expand their farms (i.e. expansionist agents). The high economic growth would also allow people coming from the urban areas to buy small farms in attractive areas where nature is an important component of the landscape. Only fields suitable for agriculture would be incorporated to other farms, whereas some fields with less suitable soils would be used to protect/develop nature. Because of the low governmental intervention, the development of the EHS would be less likely to take place in the A1 scenario than in the Trend and B2 scenarios, in particular in those areas suitable for agriculture. Finally, as a result of the lack of strong policy regulations and incentives such as agri-environmental schemes, farmers will be more likely to cut hedgerows and tree lines than in the other two scenarios, and they will not have any incentive to plant new elements.

B2 scenario

This scenario corresponds to a regionalised world, where solidarity and regionalisation are the key drivers of the socio-economic development (MNP and RIVM, 2004). For the Dutch agriculture, this regionalisation represents the protection of agriculture represented in a continuation of the CAP, the milk quota and the income support policies. In addition, key policies related to environment, nature and animal welfare are expected to be implemented. This leads to a diversification of farm practices, a limited expansion of farms or increase of the production scale, and the interconnection between different landscape functions. Still, the number of farms is expected to drop, affecting mainly dairy and mixed farms (de Bont et al., 2007). As policy regulations to promote multifunctional agriculture (i.e. second pillar of the CAP) are expected to be adopted, the viability of farms owned by farmers willing to diversify farm practices would increase, in particular those farmers in areas where cultural and environmental values are higher (i.e. National Landscape). Due to the regionalisation of the agricultural sector, land abandonment is not expected. Available land would be incorporated in other farms or it would be purchased to develop the EHS. This means, that the development of the EHS would continue and it would be higher than in the Trend scenario due to an active role of the government to purchase land. Finally, the reinforcement of programmes of the second pillar of the CAP (e.g. agri-environmental schemes and LEADER+) would promote the restoration and management of hedgerows and tree lines. Still, these landscape elements might be relocated or removed depending on the suitability of the fields for agriculture and farmers' willingness to protect them.

The specific assumptions concerning farmers' decision-making as implemented in the model for these scenarios are summarised in Appendix A.

3 RESULTS AND DISCUSSIONS

In this section, we describe and analyse the different simulation results. Firstly, we look at the landscape changes in the different scenarios. Secondly, we analyse the relation between these changes and the diversity of decision-making. Thirdly, we describe the outcome of the expert validation of the modelling results for the different scenarios. Finally, we present some limitations of the approach used in this chapter.

Table 4.2. Percentage of the total area of the region covered by each landscape class and percentage of the area of each landscape class that has a low suitability for agriculture for the current patterns and the simulated results of the different scenarios.

Landscape class	Current patterns		Trend scenario		A1 scenario		B2 scenario	
	Area	Low suitability	Area	Low suitability	Area	Low suitability	Area	Low suitability
1	12.5	27.7	7.4	35.9	13.4	12.2	6.0	37.4
2	17.2	9.7	10.2	13.3	10.0	3.9	10.0	15.5
3	23.2	38.1	24.3	28.9	27.9	25.2	21.1	27.5
4	35.3	28.2	35.2	19.6	26.6	23.8	35.7	21.7
5	7.1	89.0	11.1	80.4	12.6	84.0	11.4	71.2
6	4.8	93.8	11.9	66.1	9.7	91.1	15.8	58.3

3.1 Landscape changes

In all three scenarios, there is an increase in area of landscapes with high density of nature areas (Table 4.2 and Figure 4.1). This increase is accompanied by a decrease in area of most landscapes with low density of nature areas. These changes in landscapes classes reflect the development of nature in all three scenarios, in particular the development of the EHS (Figure 4.2). Yet, several differences between the scenarios can be observed. In the Trend and B2 scenarios the development of nature is related to the development of the EHS, taking place all throughout the region. This development reflects the role of the government in the process of nature development in these two scenarios. In the A1 scenario, the development of nature is not only restricted to the EHS, taking place in areas with low suitability for agriculture. The high rate of abandonment in this scenario reflects the low economic viability of many farms in a more globalised economy. As the current location of nature is already concentrated in areas with low suitability for agriculture, the increase of landscape with high density of nature in the A1 scenario only occurs next to the existent locations. Similarly, landscapes with low density of nature areas often remain unchanged in the A1 as a result of the high demand for land with high suitability for agriculture.

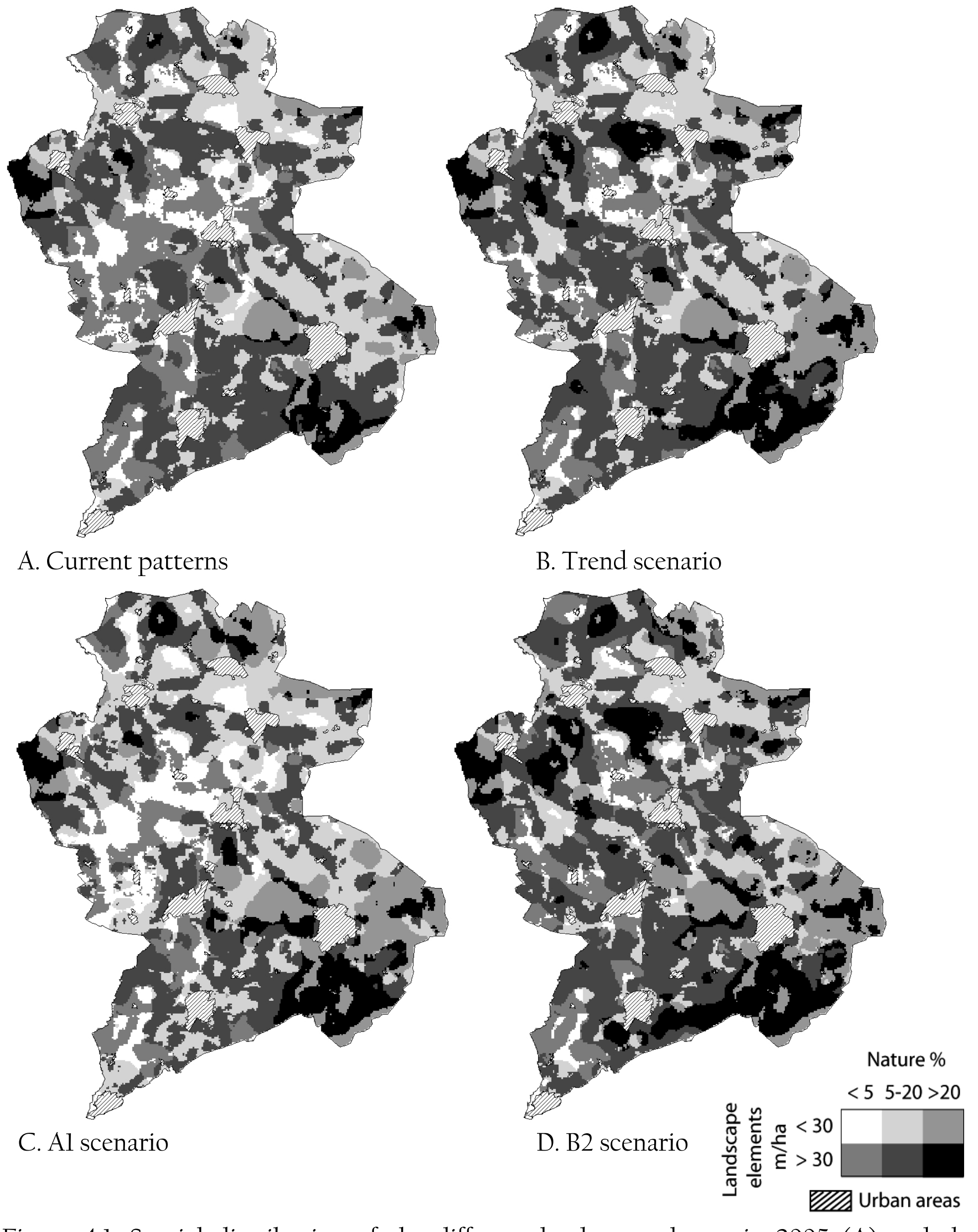

Figure 4.1. Spatial distribution of the different landscape classes in 2005 (A) and the simulation results for 2020 for the Trend (B), A1 (C) and B2 scenario (D).

Compared to the current patterns, most of the area that is currently covered with landscapes with high density of nature areas does not change to another class in any scenario (Table 4.3). In the A1 scenario, part of the area of landscapes with hedgerows and tree lines changes to landscape classes with few of these elements, in particular landscape class 2 and 4. This is the consequence of the reduction in the number of fields with landscape elements, which principally takes place in areas suitable for agriculture. These changes are caused by the low intervention of the government in the rural development of the area in this scenario. In the B2 scenario, the amount of change is much lower than in the A1 scenario. Additionally, in the B2 scenario almost 10% of landscapes with few hedgerows and tree lines change to landscapes classes with many of these landscape elements. These changes are caused by the fact that the number of fields with these elements in the B2 scenario remains almost constant, and even in some areas of the region it increases, reflecting the reinforcement of policy regulations to protect these landscape elements in this scenario. Nevertheless, changes in the density of landscape elements within fields do not largely affect the spatial extent of the different landscape classes in the A1 and B2 scenarios. This indicates that changes between landscape classes in the region will be primarily the consequence of processes of nature development. This relatively small influence of the density of landscape elements is caused by the fact that a large part of these elements are located outside the agricultural fields (e.g. along roads and canals). In addition, changes in landscape types in the B2 scenario do not largely deviate from those of the Trend scenario. This resemblance in landscape structure reflects the similarity between the assumed policy regulations for the B2 scenario and those currently in place in the region such as the Reconstruction Act—a development plan to develop further the region based on social, economic and environmental objectives (Provinciale Staten van Gelderland, 2005b).

Changes in landscape classes have an impact in the character of the landscape in all scenarios. The further concentration of landscape classes with nature areas and the decrease of landscapes with landscape elements in the A1 scenario show how the landscape in the region would change causing a process of polarisation between open landscapes in areas suitable for agriculture and marginalisation in areas less suitable for agriculture. The loss of both cultural elements (i.e. hedgerows and tree lines) and agricultural area would affect the traditional character of the region. This polarisation between marginalisation and consolidation has been described for other rural regions in Europe as well (e.g. Poudevigne et al., 1997; Kristensen, 1999), specially in mountain regions (Baldock et al., 1996; MacDonald et al., 2000). In contrast, a process of polarisation does not occur in the Trend and B2 scenarios, reflecting the regional development assumed in those two scenarios. In fact, an increase of landscape with medium and high density of nature areas takes place also in areas suitable for agriculture. These changes in landscape classes are the consequence of an increase in the interconnection between nature and agriculture. This increase together with maintenance and development of landscapes with hedgerows and tree lines reinforce the distinctive character of this rural region, in particular of those areas currently dominated by agriculture. Still, this process of interconnection represents a loss of some agricultural area, which might affect the traditional agrarian character in parts of the region, in particular in the designated National Landscape.

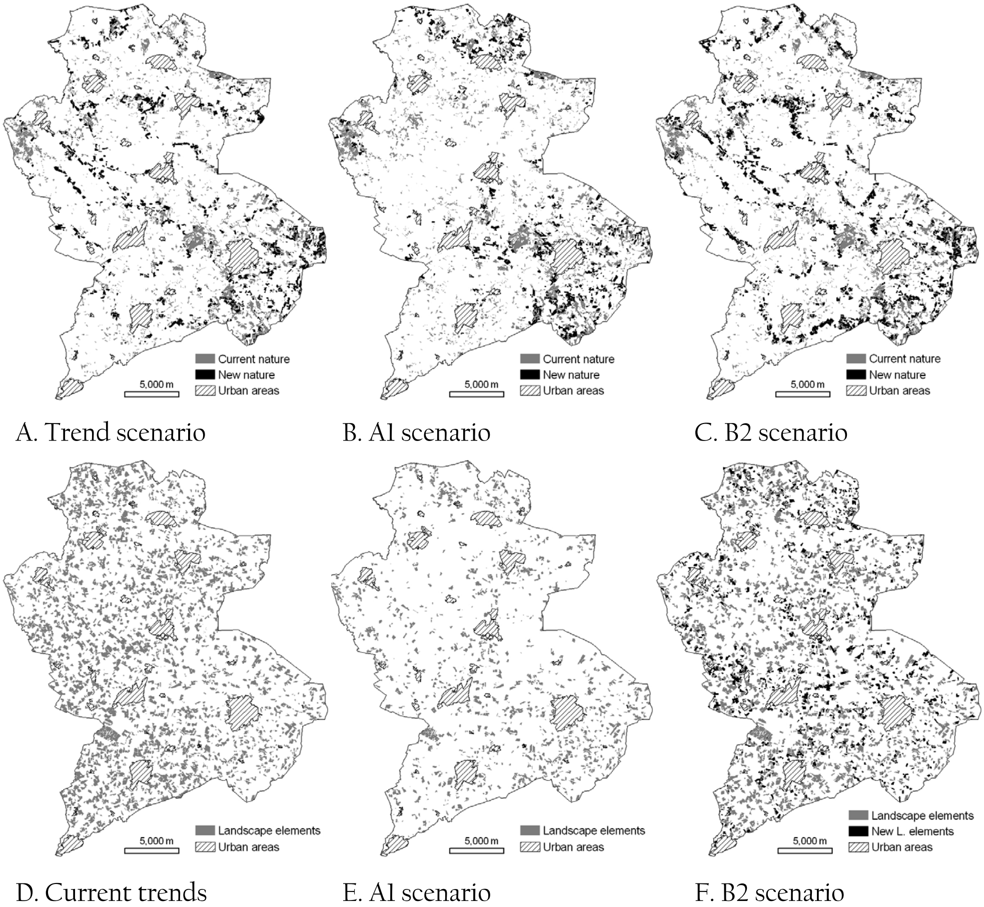

Figure 4.2. Comparison between the current landscape patterns and the scenario results. Changes in nature areas in the Trend (A), A1 (B) and B2 scenarios (C). Current patterns (D) and changes in landscape elements in A1 (E) and B2 scenarios (F).

3.2 Agents' decision-making

Differences in the proportion of agents' decisions per agent type can be distinguished between the simulated scenarios, affecting the structure of the agent population of the region (Table 4.4). For farm cessation, both the number of agents who stop farming and the difference of this number between scenarios are much larger for non-expansionists than for expansionist agents. For farm expansion, hobby agents are less likely either to buy or sell land than non-expansionist agents, while the farm size of expansionist agents largely increases in all three scenarios, in particular in the A1 scenario. Finally, for the protection of landscape elements, less diversifier and expansionist-diversifier agents cut these elements in the A1 and B2 scenarios, whereas more of them plant these elements in the B2 scenario (Table 4.5). Expansionist-conventional agents cut these elements more than any other agent type and few hobby agents cut or plant them in the A1 or B2 scenarios.

Table 4.3. Cross-tables comparing the percentage of area of the current landscape classes to the simulated results for each scenario

	Landscape class	Current patterns					
		1	2	3	4	5	6
Trend scenario	1	59	0	0	0	0	0
	2	0	59	0	0	0	0
	3	41	0	83	0	0	0
	4	0	40	0	80	0	0
	5	0	0	17	0	100	0
	6	0	1	0	20	0	100
A1 scenario	1	74	24	0	0	0	0
	2	0	58	0	0	0	0
	3	26	4	78	17	0	0
	4	0	14	0	68	0	0
	5	0	0	22	1	100	3
	6	0	0	0	14	0	97
B2 scenario	1	45	2	0	0	0	0
	2	9	52	0	0	0	0
	3	39	3	65	2	0	0
	4	6	40	11	73	0	0
	5	1	0	20	0	91	0
	6	0	3	4	25	9	100

When looking specifically at how each agent type affects the landscape in the different scenarios, several relations between decision-making and landscape structure can be distinguished. The processes of farm cessation and farm expansion in all three scenarios cause an increase in the differences of the total area managed by each agent type (Table 4.4). In fact, expansionist-conventional agents manage approximately two thirds of the total agricultural area of the region in all scenarios, while hobby, conventional and diversifier agents manage together 26%, 17.9% and 23.2% of the land in the Trend, A1 and B2 scenarios respectively. As expansionist-conventional agents manage a large part of the region and as they cut landscape elements more than any other agent type in the A1 and B2 scenarios, these agents have an active central role in changing the landscape structure of the region, especially in the polarisation of the landscape described for the A1 scenario. Although expansionist-diversifier agents have an opposite role by planting more and cutting less landscape elements, the area they manage in all scenarios only reaches approx 13%. Similarly, conventional and diversifier agents play an active role in the landscape, but the area they manage does not exceed 20% of the total agricultural area in any scenario. Nevertheless non-expansionist agents, including hobby agents, are the main source of land for the development of nature and for farm expansion of other agents in all three scenarios. This means that these non-expansionist agent types play a more passive role in changes in the landscape structure of the region, including both the polarisation of the landscape described for the A1 and the interconnection of the landscape described for the Trend and B2 scenarios. Additionally, as hobby agents are unlikely to cut or plant landscape elements, they limit to some extent changes in the scale and in the homogeneity of the landscape. Still this process is localised as around half of the hobby agents stop farming by 2020 and they only manage a small area of the region in all scenarios. Nonetheless, some studies have showed that instead of being passive, hobby farmers are more active in changing the structure of the landscape than full-time farmers (Primdahl, 1999; Kristensen, 2003). This discrepancy in the results is caused by the selection of variables and the assumption that hedgerows and tree lines would be only planted because of changes in policy regulations, in which hobby agents often do not participate (Chapter 2; Valbuena et al., 2008).

Table 4.4. Number of agents in 2005, percentage of the area managed and percentage of agents who stop farming per agent type in the different scenarios for the year 2020.

Agent type	Current		Trend scenario		A1 scenario		B2 scenario	
	N	Area %	Stop %	Area %	Stop %	Area %	Stop %	Area %
Hobby	1036	11.7	46.0	7.9	54.0	6.6	51.3	6.7
Conventional	531	20.2	46.1	11.7	67.8	7.0	58.2	10.3
Diversifier	291	10.0	43.0	6.4	59.5	4.3	43.6	6.2
Expansionist conventional	750	49.5	7.3	62.4	10.3	69.2	10.1	64.8
Expansionist diversifier	133	8.5	5.3	11.5	7.5	13.0	4.5	12.0

Table 4.5. Average farm size and the percentage of agents per agent type who would cut or plant landscape elements in the different scenarios for the year 2020.

Agent type	Current	Trend	A1 scenario		B2 scenario		
	Farm size (ha)	Farm size (ha)	Farm size (ha)	Cut %	Farm size (ha)	Cut %	Plant %
Hobby	4.7	5.6	5.5	3.8	5.1	0.8	2.8
Conventional	16.0	16.1	16.3	46.8	17.8	15.3	33.8
Diversifier	14.4	15.1	14.4	32.2	14.5	4.9	50.0
Expansionist conventional	27.7	35.2	41.0	70.7	36.9	27.0	27.4
Expansionist diversifier	26.9	35.8	42.1	48.8	36.3	10.2	56.7

The dominant role of a single agent type might reduce the relevance of differentiating different farming decision-making to study the changes in landscape structure in this rural region. This suggests that the spatial patterns obtained using approaches that assume a single algorithm to represent land-use decisions might have been similar to those presented in this chapter, even with less data requirements. Nevertheless, the design and use of a model based on the diversity of decision-making allows us to connect micro-scale and macro-phenomena by the differentiation of individual and heterogeneous decision-makers as suggested by Matthews et al. (2007). Still, as argued by Verburg (2006), the choice of using models based on either single or multiple algorithms to represent decision-making would depend on the objective of the research itself.

Despite the differences in landscape structure between scenarios, the proportion of nature and the density of landscape elements do not always depend on farmers' decisions: a large part of hedgerows and tree lines are outside the farms while nature areas are mainly managed by non-agricultural organisations. This explains why despite the large differences in individual decisions between scenarios, parts of the characteristic landscape structure of the region would remain in all scenarios. This stability of the landscape is represented not only by the past and current trends in the region, but also by the views of different stakeholders (see van der Kolk et al., 2007).

3.3 Expert validation

All the experts agreed that the simulated results for the different scenarios were plausible. Although most of them agreed with the amount and location of the landscape changes in each scenario, some of them had doubts about the current distribution of landscape elements within agricultural fields represented by the database used in this study. Concerns were raised specifically on the larger number of fields with these elements in landscapes dominated by agriculture as compared with those with a high density of nature areas. This discrepancy relates not to the number or length of the landscape elements, but to their width. In general, landscape elements in areas with high density of nature areas are wider than those located in landscapes dominated by agriculture. This means that for future research, the width of landscape elements need to be considered in this kind of analysis.

Related to the scenario description, experts agreed with most of the underlying assumptions. Nevertheless they had some remarks. Firstly, experts mentioned that the current development of the EHS does not only occur by purchasing land from farmers, but also by the farmers themselves, a process not represented in the model. Secondly, processes of land consolidation are taking place in some locations of the region. This means that some changes in the number and location of landscape elements within fields are also expected in the Trend scenario. Thirdly, migration processes of people from the city to the study area assumed only for the A1 scenario are already happening. Fourthly, the amount of farmers who would stop farming and the average farm size might be much higher than the presented in this chapter, specifically in the A1 scenario. Finally, hobby farmers play an active role in changing the landscape structure, and even some of them participate in policies to protect and manage nature and landscape. All these remarks support the statement of Matthews et al. (2007) that an early involvement of stakeholders in the modelling process help us to reduce the uncertainty attached to the analysis of these complex human-environmental systems.

3.4 Limitations

The empirical approach described in this chapter faces some limitations. Firstly, the cutting and planting of hedgerows and tree lines are processes not only related to the farm, but also to the structure of the field (Baudry, 1989). Often, removal of landscape elements is directly related to changes in field size. To make a better link between farmers' decisions and the effect on the structure of the landscape, future research should also include changes at the field level (Gaucherel et al., 2006; Jellema et al., 2009). Secondly, the response of individual decisions to the exogenous factors of a region was analysed based on the past and current farmers' willingness, assuming that they are constant. Thirdly, the quantification of the response of farmers' decisions to future changes in these exogenous factors was sometimes based on expert knowledge and not on empirical data given limitations on data availability. Finally, the influence of social networks and institutions, which were not directly included in this study, plays an important role in farmers' decisions-making process in rural regions in Europe, in particular in the Netherlands (Oerlemans and Assouline, 2004; Franks and Mc Gloin, 2007).

4 CONCLUSIONS

The current landscape patterns of the study area already show a separation between areas dominated by agriculture and areas where an interconnection between nature and agriculture exists. The continuation or reinforcement of the current policy regulations would enhance the interconnection between nature and agriculture by further developing the EHS and programmes aimed to improve and manage nature and the landscape. In contrast, revoking these regulations and favouring the liberalisation of agriculture would deepen the process of polarisation between nature and agriculture, causing a loss of cultural and natural values in the region. In addition, although the dynamics of the landscape patterns of the region do not totally depend on farmers' actions, different decision-making strategies would affect differently the landscape structure. While some strategies would have an active role in changing the landscape, others would be more passive. The importance of this effect would depend not only on the decision-making strategy itself, but also on the amount of land that each strategy manages and on the analysed processes. Still, as mentioned by Kristensen (2003), even if some strategies manage a small portion of the total agricultural area, their decisions can influence natural and cultural values of the landscape as a whole.

The results of this chapter emphasise the added value of including the diversity of farming decision-making in regional land-use research. By including this diversity, we are able to understand better why and how local communities would influence the landscape in response to exogenous processes of rural regions (van den Bor et al., 1997). In land-use research, the use of regional approaches that include interactions between actors and factors at different social and spatial levels gives us the opportunity to analyse and explore regional LUCC as a result not only of the exogenous processes, but also of the endogenous processes, including the individuals involved in LUCC (Parker et al., 2003; Manson, 2005). In particular, as the future of many rural regions depends on the dynamics of exogenous processes and as the European legislation continues moving towards voluntary mechanisms and the reinforcement of multifunctional agriculture as a basis for rural development (European Commission, 2006), the use of these modelling approaches, as argued by Piorr et al. (2009), offers an alternative to analyse, explore and discuss the impact of farming on the landscape in rural regions under different future alternatives.

APPENDIX A. MODELLING DESCRIPTION

The application of the modelling framework in this chapter was carried out by using NetLogo 4.0. A run of the model consisted in 15 time steps or years. Four main land-use types were defined (urban areas, nature, water bodies and agricultural land). Three main decision-making processes were selected: farm cessation, farm expansion and protection of landscape elements (see below). Each agent owned one or several fields, each field was formed by one or several pixels and a pixel represented one hectare. Agents characteristics include agent type, age, owned farm, owned fields, farm size, agribusiness type, production scale, memory (actions of the previous 5 years), location (within or outside the National Landscape) and probabilities for each decision-making processes. The initial probability of each agent was established based on the available historical data of the sample survey and census data. As some of the empirical data were gathered with a temporal scale of 5 years, they were re-scaled to 1 year. Agents' options, periodicity, initial conditions and used variables were different for the three simulated processes (table A1). For each scenario, specific assumptions of agents' decision-making were defined consistent with the scenario description. Table A2 gives an overview of these scenario specific assumptions.

Table A1. Overview of simulated processes and variables used to define agents' initial conditions, options and decisions and select the fields.

Process	Options	Periodicity	Initial condition	Variables: agent-level	Variables: field-level
Farm cessation	Stop Inherit	Once	Age Previous actions	Agent type Agribusiness type Previous actions	Location
Farm expansion	Sell Keep Buy	Every year	Previous actions	Agent type Farm size Previous decision Previous actions	Distance to owner Location in or out the EHS
Protection landscape elements	Cut Keep Plant	Once each 6 years	None	Agent type Previous actions	Suitability for agriculture Current density

Pixel characteristics include field number, field size, owner, land-use type, production per hectare, density of landscape elements inside and outside the agricultural field, distance to the owner and suitability for agriculture. The suitability for agriculture was calculated by using a logistic regression model, where 1 represented current agriculture land and 0 other land uses. To avoid spatial autocorrelation, only 20% of the pixels of the total area were randomly selected. The selection of the independent variables was based on a combination of values of the variance inflation factor (VIF) and expert knowledge. The VIF is a method to calculate the degree of multicollinearity of the different independent variables (Hair et al., 1998). Values lower than 10 were included in the logistic regression analysis. The original set of independent variables included soil characteristics (texture, structure, groundwater table and pH), an indicator whether land consolidation processes had taken place and when, and neighbourhood characteristics (amount of surrounding nature and average field size within a radius of 1 Km). Based on the logistic regression analysis, only variables related to land restructuring and neighbourhood were significant and were included into the model.

Table A2. Input data of the ABM model for the different scenarios for each decision-making processes.

		Trend scenario	A1 scenario	B2 scenario
Farm cessation	Expected overall percentage of agents that stop farming between 2005-2020	32%	46%*	36%*
	Specific percentage of agents that stop farming between 2005-2010 per agribusiness type	No differences between agribusiness types	Dairy 55%; arable 52%; intensive livestock 55%; mixed 53%; and other herbivore farms 35%*	Dairy 51%; arable 26%; intensive livestock 51%; mixed 46%; and other herbivore farms 30%*
	Incentives for multi-functional agriculture (CAP)	No	No	Diversifiers: 10% less likely to stop. Agents in the National Landscape: 10% less likely to stop.
	Immigration	No	Hobby agents with farms surrounded by more than 10% of nature are likely (50%) to sell them to new hobby agents.	No
Farm expansion	Buying capacity	10% more than census data	20% more than Trend	Same as Trend
	EHS	Fields sold that are located in the EHS are converted to nature.	Fields with low suitability and located in the EHS are likely (50%) to be converted into nature.	The likelihood that an agent who owns fields in the EHS sells land is the double than for others. When selling land, fields in the EHS are sold first.
	Land abandonment	No	Fields to be sold and with low suitability for agriculture are likely (50%) to be abandoned.	No
Protection**	Influence of policies related to hedgerows and tree lines	No	Elements in fields suitable for agriculture are cut.	Elements in fields suitable for agriculture are cut. Elements are more likely to be planted in fields less suitable for agriculture.

* After de Bont et al. (2007)

** Protection of hedgerows and tree lines

The model was set up with all the socio-economic and spatial characteristics of both agents and pixels. In every time step, agents decided first whether they would stop farming or inherit their farm (Figure A). Then, they decided to buy, keep or sell their fields. Next, they decided to cut, keep or plant landscape elements in their fields. Finally, the landscape was updated.

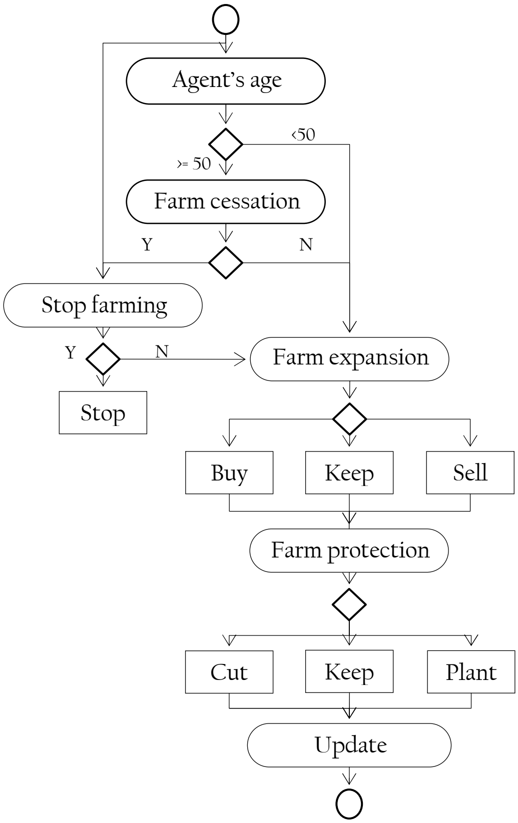

Figure A. Flow chart of the scheduling of the model for a time step.

Farm cessation

When agents were 50 years old or older, they were assumed to decide whether to stop farming or inherit their farm. Agents were only able to take this decision once, but there was a time lag between the decision and the real action of stop farming. Still, all agents had to stop farming or inherited the farm before they were 85 years old. To avoid selling big farms to single buyers, agents with farms bigger than five fields sold different parts of their farm to different buyers. It was assumed that the selection of a buyer depended on her/his distance to owner, to her/his agent type and to the agent's buying capacity represented as her/his farm size. Finally, if an agent was an expansionist and decided stop farming, s/he would change her/his strategy and became a non-expansionist agent (i.e. transitional rupture).

For the initial probability and based on the empirical data of the sample survey, agents older than 50 years and who had bought land the previous five years were less likely to stop farming (6%) than those who had not acquired any land (34%). Decision on farm cessation depended on several factors such as agent type, agribusiness type and previous actions. Related to agent type, expansionist agents were less likely to stop farming (5%) than non-expansionist (30%). Also, agents with agribusiness type dairy and intensive livestock farms were in general more likely to stop than agents with other agribusiness types. Similar to the initial conditions, previous agents' actions on farm expansion affected the likelihood to stop farming.

Farm expansion

After the decision on farm cessation or when agents were younger than 50 years old, agents decided whether to buy, keep or sell land. The initial probability for this decision was calculated based on whether agents had previously bought or sold land (census data 2001 and 2005). Agents who had bought land only had the options to keep or buy more land. Decisions on farm expansion also depended on the agent type, farm size and agent's previous decisions and actions. Related to agent type, expansionist agents were more likely to buy land (60%) and less likely to sell it (0.1%) than non-expansionist (30% and 5% respectively). In particular, the likelihood that hobby agents would buy land was very low (1%) due to either their lack of interest or impossibility to expand their farms. In addition, agents with larger farms had a higher capacity to buy land than those with smaller farms. Also, agents who had bought land in the previous 5 years were less likely to buy more land, depending on the amount of acquired land (i.e. internal feedback). This buying capacity was not static as it depended on the mean farm size of the whole agent population for a certain time step. Further, it was assumed that agents who had decided to stop farming were not able to buy more land, whereas they were more likely to sell it. If an agent decided to sell land, s/he selected and sold the farthest field from the farmhouse.

To represent the path dependence of agents' decision-making and keep certain coherence on their decisions, previous decisions and future options were linked. Besides modifying the values of the thresholds between options due to the influence of the farm and region factors, agents' decisions were limited by drawing a random number out of a normal distribution. The amplitude of this distribution defined agents' options for a certain year, while the frequency distribution defined the most likely decision. The value of the mean of this distribution was the value of the previous decision, while the value amplitude or the standard deviation of the curve was calibrated with the model.

Protection of hedgerows and tree lines

As density of hedgerows and tree lines have not changed considerably in the last years (Koomen et al., 2007), this process was only included for the A1 and B2 scenarios. After their decision on farm expansion, agents could decide whether to plant, keep or cut hedgerows and tree lines in their farms. Only those elements located within fields were selected and represented as a characteristic of the field. Based on data of the sample survey, the probability to cut, keep or plant these elements depended on the agent type: diversifiers and expansionist-diversifier agents were less likely to cut them (20%) than conventional and expansionist-conventional agents (50%). This decision was taken every 6 years; for its initial value, a random number was drawn between 0 and 10 for each agent. The path dependence of the decision-making processes was represented as the one used for farm expansion (see above). The probability to cut or plant landscape elements depended on the field suitability for agriculture (the more suitable the more likely to cut these elements) and the current density of these elements in the field.

Chapter 5

Voluntary mechanisms and landscape changes

Abstract

In rural regions, land-use/cover change (LUCC) is often the result of the decision-making of individual farmers. To influence this decision-making, compulsory and voluntary mechanisms are implemented. However, farmers' decision-making is a heterogeneous process that depends on their ability and willingness to take certain decisions. Discrepancies between farmers' ability and willingness and the design of voluntary mechanisms occur frequently. This makes it necessary to understand how farmers' participation in these mechanisms can affect LUCC processes. The aim of this chapter is to demonstrate an agent-based approach to analyse and explore how voluntary mechanisms can influence LUCC processes in rural regions. This approach is applied to a rural region in Australia, where clearing of native vegetation takes place for agricultural development. Historical land-cover data and semi-structured interviews were used to parameterise an agent-based model. Factors that influence farmers' ability and willingness on participating in these mechanisms were identified, as well as the diversity of decision-making in the region. Three scenarios were simulated with the model to explore how the implementation of different voluntary mechanisms can affect the landscape structure of the region. This chapter discusses how the diversity of farmers' willingness and ability to participate in proposed voluntary mechanisms can influence the landscape structure in the region. The advantages and limitations of this approach in relation to land-use research and land-use policy are discussed.

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1 INTRODUCTION

Human-induced land-use/cover change (LUCC) affects the landscape and the provision of goods and services to society (de Groot et al., 2002; Willemen et al., 2008). In rural regions, agricultural practices are one of the main drivers of LUCC. For example, loss of native vegetation for agricultural production has several implications for ecosystem function, biodiversity and carbon emissions (McAlpine et al., 2009). A distinctive aspect of rural regions is that the bulk of the land is often managed by comparatively few farmers, but nonetheless, their management decisions may be extremely diverse. Therefore, it is necessary to understand how farmers take decisions and how these decisions can change. For instance, governmental organisations willing to intervene in LUCC processes try to influence farmers' decision-making. To achieve this, both compulsory and voluntary mechanisms are commonly used, including policy regulations, loans, subsidies and advice (Aarts and Woerkum, 2000).

Farmers' participation in compulsory and voluntary mechanisms are not necessarily the same. In compulsory mechanisms (e.g. policy restrictions on vegetation clearing), decision-making is often restricted, and therefore, farmers have to follow the same set of regulations—at least in those regions where the government can monitor and control the implementation of these regulations. In voluntary mechanisms (e.g. carbon credit and agri-environmental schemes), farmers are able to decide for themselves whether to participate in these mechanisms. Farmers' decisions depend on their ability and willingness (Siebert et al., 2006), as well as on the characteristics of the mechanisms themselves (Wilson and Hart, 2000; Pannell et al., 2006). While ability represents whether farmers can take certain decisions based on their resources (e.g. labour, capital and land), willingness represents whether farmers want to take such decisions. This means that farmers' ability and willingness need to be considered in order to analyse the potential effect of voluntary mechanisms on LUCC processes in rural regions.

Discrepancies between the characteristics of voluntary mechanisms and farmers' ability and willingness, such as extension support and flexibility of the mechanisms, often hamper their participation (Toogood et al., 2004; Pannell et al., 2006). Therefore, it is necessary to understand what determines farmers' ability and willingness to participate in voluntary mechanisms. Farmers' decision-making is not a homogeneous process, reflecting the diversity in the ability and willingness among farmers in rural regions (Schmitzberger et al., 2005; Siebert et al., 2006). Thus, the diversity of decision-making strategies within these regions needs also to be considered. Moreover, as LUCC is a spatial process (Veldkamp and Verburg, 2004; Aspinall, 2008), it is also necessary to investigate how farmers' decisions can influence LUCC processes at different organisational and spatial levels including the field, farm and region.

The design of agent-based modelling (ABM) offers a technique to analyse and simulate the effect of farmers' decision-making on LUCC processes of rural areas (e.g.

Chapter 3; Piorr et al., 2009; Valbuena et al., 2010). ABM is a tool with which it is possible to represent individual decision-making units, their interactions and their interaction with their environment. These characteristics give ABM the capacity to simplify, simulate and analyse the interaction between farmers, their farms and their environment (Parker et al., 2003; Matthews et al., 2007).

The aim of this chapter is to demonstrate an agent-based framework to analyse and explore how voluntary mechanisms can influence LUCC processes in rural regions. Specifically, we investigate how farmers' participation in voluntary mechanisms to restore native vegetation can influence the landscape structure in a rural region in Queensland, Australia. Recently, Queensland has experienced a rapid clearing of native vegetation (Lepers et al., 2005). Although some legislation has been introduced to protect the remnant native vegetation, mechanisms to restore and protect secondary vegetation are needed. In addition, because private land contains the majority of remnant vegetation, it is essential to convince farmers to participate in voluntary mechanisms to restore native vegetation.

2 METHODS

The study area in this chapter is the Tara region. Tara is a rural region located in the south-eastern part of Queensland, Australia. This region covers an area of ~1.2 million hectares. The agricultural sector in the Tara region includes grain, beef and wool. This region has experienced a clearing of native vegetation (see section 2.2, Chapter 1).

2.1 Native vegetation in Queensland

In Australia, agricultural land-use has been a major driver of landscape change with extensive conversion of native vegetation to crops and livestock pastures. In the last decade, different compulsory and voluntary mechanisms to protect and restore native vegetation have been either implemented or proposed. The Commonwealth and State governments have adopted policy restrictions aiming to prevent farmers from clearing the remnant native vegetation in their farms (Hamblin, 2009). In addition, the Commonwealth Government in 2008 introduced the "Caring for our Country" programme, a new natural resource management initiative that incorporates previous programmes and funding initiatives (http://www.nrm.gov.au). To restore native vegetation in rural areas, farmers can adopt voluntary mechanisms, including environmental stewardship programmes and carbon credit schemes. Environmental stewardship programmes offer economic incentives to farmers in order to retain and/or improve the cultural and/or natural values in their farms (Hajkowicz and Collins, 2009). Recently, an emission-trading scheme has been proposed to mitigate carbon emissions in Australia (Garnaut, 2008; Hunt, 2008). This trading scheme has generated debate on the potential use of carbon credit schemes as an economic mechanism not only to mitigate climate change, but also to restore native vegetation in rural regions (Gunasekera et al., 2007; WGCS, 2009). Restoring modified native vegetation offers several benefits in terms of restoring native ecosystems and their services, particularly in areas deforested recently, such as the Brigalow Belt in Queensland, Australia (Fensham and Guymer, 2009; McAlpine et al., 2009). Some of these benefits are: native vegetation does not require the intensive effort of planting; it includes natural tree species that are already adapted to the region; and it can restore native ecosystems and biodiversity in fragmented landscapes (Fensham and Guymer, 2009).

In 1994 and 1999, the Queensland government introduced the Land Act and the Vegetation Management Act, limiting the broad-scale clearing of remnant native vegetation of some bioregional ecosystems on both leased and freehold land. Bioregional ecosystems represent native vegetation communities with similar climate, geology, landform, soils and vegetation associations (Sattler and Williams, 1999). Each bioregional ecosystem was allocated a biodiversity status classification based on the relative amount of area covered by remnant native vegetation. The 1999 Vegetation Management Act protected only endangered bioregional ecosystems (<10% remaining) and resulted in rapid clearing of non-protected remnant vegetation in many areas. In 2004, therefore, the "Vegetation Management and Other Legislation Amendment Bill" was passed prohibiting the clearing of all remnant native vegetation. Early in 2009, the Queensland government imposed a moratorium on the clearing of endangered secondary vegetation, including brigalow. This moratorium was lifted in October 2009 and replaced by the Vegetation Management (Regrowth Clearing Moratorium) Act, which has modest restrictions on the clearing of secondary vegetation of endangered ecosystems.

2.2 Agent-based approach

Semi-structured interviews were conducted to capture farmers' views on voluntary mechanisms, including carbon credit schemes and stewardship payments. An empirical ABM was built to include farmers' willingness and ability, including an agent typology to simplify the diversity of decision-making in the region. This ABM was used to simulate three different scenarios, which represented the implementation of different voluntary mechanisms in the study area.

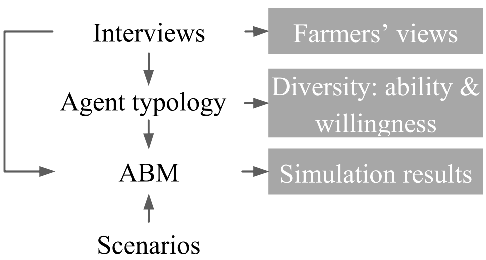


Figure 5.1. Overview of the method used in this chapter.

Interviews

In total, 30 semi-structured interviews were conducted in the region during September and October 2009. The interviews focused on farm characteristics, farmers' views on the future of farming and native vegetation, and farmers' willingness to participate in voluntary mechanisms to restore native vegetation. Although most of the interview was based on a questionnaire using Likert-type scales, farmers were encouraged to elaborate on their answers. Interview data were mainly used to identify what could determine farmers' ability and willingness to participate in voluntary mechanisms to restore native vegetation (Figure 5.1). These data were also used to corroborate the agent typology (see section Agent-based modelling framework) and to understand better the management of native vegetation in the study area (i.e., reasons and location of previous decisions)—which was used to parameterise the model.

Gaining access to farmers in the region is difficult, with many farmers reluctant to talk to researchers and highly sceptical of government intervention (Seabrook et al., 2008). For this reason, a snowball sampling technique was used to contact new potential respondents who may be willing to participate. This resulted in a biased sample towards farmers who were interested in participating in voluntary mechanisms to restore native vegetation. To help overcome this bias, we asked farmers to elaborate on the decision-making of their neighbours—especially those who were possibly more reluctant to participate in this study. Although this method is sensitive to bias, it provides us with a better overview on the diversity of decision-making of the region.

Agent-based modelling framework

The generic modelling framework described in Chapter 3 (Valbuena et al., 2010) was used to simplify, analyse and represent farmers' decision-making within rural regions. This framework was applied to the study area (simulation period 2007 to 2022), in particular to farmers' participation in voluntary mechanisms to restore native vegetation in their farms. The agent typology was built based on structural characteristics of the farm, specifically farm size and agribusiness type. This selection was made in order to combine the available data and key characteristics distinguishing differences in decision-making in the region. The availability of cadastral data and land-cover data of different years for the whole region, and the lack of socio-economic data at a farm level made these characteristics the best choice. Farm size was identified as one of the main factors explaining why farmers have kept native vegetation in their farms in the region (Seabrook et al., 2008). Farms with different agribusiness type are assumed to manage native vegetation differently. It is observed that crop farms are likely to have less native vegetation than mixed farms. Crop farms were defined as those with more than 30% of their area covered by crops. Large farms were defined as those bigger than 2000 ha, which was the average farm size in the region. Based on the combination of these two structural characteristics four different agent types were identified: "mixed farms", "crop farms", "large mixed farms" and "large crop farms". ANOVA analyses were conducted to verify whether the spatial structure, location and previous changes in land-cover were significantly different between agent types for the whole population.

The spatial structure was characterised by the proportion of the farm covered with remnant native vegetation, secondary vegetation, soils, endangered regional ecosystems and cleared area between 1999 and 2005. These spatial structure indicators were derived by combining cadastral, soil and regional ecosystems maps, and the 1999, 2005 and 2007 land-cover maps produced by the Queensland Statewide Government Landcover and Trees Study (SLATS). Historical land-cover data and data gathered in the interviews were used to parameterise the probabilities of the agents' decision-making process. The likelihood of protecting or clearing secondary vegetation was estimated by using the amount of native vegetation in the farms (land-cover data 2007), and the frequency and amount of previous land-cover changes per agent type for the whole region (land-cover data 1999 to 2005). Interview data were used to determine the options of each agent type in each scenario and to translate agents' decisions into changes in the location and structure of the landscape. With this information, the decision-making process of protecting or clearing secondary vegetation was defined. If agents were willing to protect it, they would choose the areas within the field selected for protection of secondary vegetation for each scenario. If agents were not willing to protect it or there were none of such areas in the field, they would clear the entire field (see Appendix B).

To compare the results on the spatial structure of the landscape of the different scenarios simulated with the model, the total area and density of native vegetation (including secondary vegetation), and the relative amount of regional ecosystems classified as endangered and of concern were calculated. To visualise changes in native vegetation for the whole region, neighbourhood analyses were carried out, where the average number of pixels with an increase of native vegetation was calculated in a surrounding area of 3 Km.

Scenarios

Scenarios are tools that help us to deal with the uncertainty attached to the future dynamics of human-environmental systems, including land-use decisions. Three scenarios were simulated using the modelling framework described above (Figure 5.1). These scenarios were described based on possible differences in the design of voluntary mechanisms to restore native vegetation in the study area. These differences are assumed to influence farmers' willingness to participate in such mechanisms. For each scenario the effects on the spatial structure of native vegetation will be evaluated. The scenarios include:

- *Baseline scenario:* this represents the current situation, where few voluntary mechanisms to restore native vegetation are implemented. As a result of this lack of mechanisms, protection of secondary vegetation depends on farmers' willingness and is likely to be low.
- *Broad protection scenario*: in this scenario, voluntary mechanisms to restore secondary vegetation are assumed to be implemented. These mechanisms would aim at protecting any bioregional ecosystem in the study area. This availability of voluntary mechanisms is assumed to boost farmers' participation by increasing their willingness to restore native vegetation.

- *Endangered ecosystems scenario*: also in this scenario, voluntary mechanisms to restore secondary vegetation are assumed to be implemented. Compared with the previous scenario, these mechanisms are assumed to aim only at restoring bioregional ecosystems that are endangered or of concern. This means that although farmers' willingness to restore native vegetation would increase, their participation in these mechanisms depends on the specific location of their farm.

3 RESULTS

We first describe farmers' views on what determines farmers' ability and willingness related to the characteristics of the voluntary mechanisms, in particular carbon credit and stewardship schemes. Next, we look at the diversity of decision-making in the study area. Finally, we describe how changes in farmers' willingness to participate in restoration programmes can affect the landscape structure in the different scenarios simulated with the ABM.

Based on the interviews, farmers' views and concerns about their participation in voluntary mechanisms to restore native vegetation can be divided in three main groups:

- **Government and regulations:** Farmers expressed a general lack of trust in the government and in this kind of mechanisms for a number of reasons. In the last decades, policy regulations have drastically shifted from stimulating the clearing of land (to obtain ownership rights) to forbidding the clearing of native vegetation. Farmers perceive this as a risk that the discourse behind these regulations can change again in the next decades. In addition, farmers have the opinion that the communication between farmers and the government is poor. This is reflected in both misinformation and lack of information about the voluntary mechanisms—particularly about carbon credit schemes. For example, it is not clear why soil carbon is not being considered in such schemes. Finally, farmers with woody vegetation on their farms think that instead of recognising their contribution, current policy restrictions penalise those who did protect native vegetation in the past and not those who cleared it completely.
- **Attitudes and beliefs:** From the interviews three main issues emerge related to farmers' attitudes and beliefs. First, the concept of growing trees is not fully embraced. Farmers see themselves as producers of food and fibre and not as tree growers. Moreover, they find little economic or ecological value in secondary vegetation—specifically in brigalow. In fact, farmers have spent considerable time and economic resources to clear or control brigalow vegetation. Also, farmers think that the general public blames them for the current environmental problems, while not acknowledging the fact that farmers provide food. Second, although some farmers see regulations on vegetation management as necessary, they would prefer to keep flexibility in their decisions. Also, some terms of the current or proposed mechanisms are not very attractive for them. Finally, an approach that includes also the neighbouring farms seems to be rather complicated. According to them, this is caused by a lack of

interaction and cooperation between farmers in the area reflecting both work overload and the weakening of regional organisations such as Landcare groups.

- **Income and productivity:** As farming is a business, the adoption of mechanisms to restore native vegetation can bring economic losses. Farmers have the opinion that if they are supposed to use productive agricultural land for native vegetation, they need to be economically compensated with at least what they would receive from agricultural production (opportunity costs). This compensation could be a yearly payment, a tax exemption or an offset of their CO_2 emissions. However, these opportunity costs would vary depending on the suitability of the soils: shallow sandy ridges are less suitable for agriculture than clay plains. Related to this, farmers mentioned that often the less land you have locked for nature restoration/protection, the higher chance to get a better price upon selling the farm. Also, farmers with mixed farms tend to value more woody vegetation than those with crop farms because trees can be directly incorporated in livestock management system (shelter and shade). Furthermore, the establishment and management of secondary vegetation require time and money. Hiring labour in the region is difficult and costly, and farmers do not want to bear this cost. Moreover, water is a limiting factor in the area and it can affect the growth and mortality of trees in the region, which represents a key challenge to carbon credit schemes in the region. Finally, many farmers have problems with feral animals and macropods, particularly during draughts. Feral animals and macropods prefer to shelter in forest during the day, so increasing the impact of these animals on farm productivity.

The results of the ANOVA analysis showed that the identified agent types are significantly different ($p < 0.01$) in terms of some of the spatial variables used to describe their farms, their location and land-cover (Table 5.1). Based on the agent typology and the interview data different decision-making strategies in terms of ability and willingness are defined.

- *Crop farm agents:* The opportunity costs of these agents to restore native vegetation tend to be the highest of all agent types. Their farms tend to be relatively small, with a high economic value, high proportion of fertile clay soils and crop land, and close to the main town. Additionally, their farms tend to have a low proportion of native vegetation cover. Based on this observation and the interviews it is assumed that their willingness to participate in voluntary mechanisms to restore native vegetation would be relatively low.
- *Mixed farm agents*: The opportunity costs of these agents to restore native vegetation tend to be relatively higher than for "large mixed agents" because of the smaller size of their farms, the higher value of their land, the higher proportion of clay soils and the shorter distance to the main town. However, as these agents are located closer to the town, they are more likely to find an off-farm job. In general, these agents still have a relatively high proportion of vegetation cover in their farms and they have been active

in clearing vegetation. This means that their willingness to participate in mechanism to restore native vegetation is still higher than for agents with crop farms.

- *Large crop farm agents* the opportunity costs of these agents to restore native vegetation tend to be relatively high. Although their farms are often large and far from the main town, they have a high economic value and high proportion of relative fertile clay soils and crop land. Further, their farms tend to have a low proportion of vegetation cover, and therefore, their role in vegetation clearing has been low. This translates in a potential low willingness to participate in mechanism to restore native vegetation.
- *Large mixed farm agents* the opportunity costs of these agents to restore native vegetation tend to be the lowest of all agent types. Their farms are generally large, with a low economic value, low proportion of clay soils and crop land, and far from the main town. Moreover, their farms tend to have a high proportion of vegetation cover and their role in vegetation clearing has also been active. This translates in a potential high willingness to participate in mechanisms to restore native vegetation.

Table 5.1. Differences in farm characteristics and percentage of vegetation cover and cleared land between agent types[a].

Agent type	N	Farm size	Crop	Value[b]	Clay soils	Distance town	Woody vegetation			Cleared[f]	
		ha	%	AU$/ha	%	Km	Total[c]	Remnant[d]	Second[e]	N	Area[g]
Crop farm	111	1201	56	344	85	39	10	5	2	34	6
Mixed farm	186	1040	7	264	71	39	20	9	6	50	20
Large crop	84	3106	53	284	79	65	12	7	3	49	14
Large mixed	113	3605	11	191	57	65	28	19	4	82	60
Total agents	494	2014	27	269	72	49	19	10	4	54	100

[a] Besides number of agents, all variables were significantly different between agent types ($p < 0.01$).
[b] Based on cadastral data 2006.
[c] Based on SLATS data 2007.
[d] Based on the "Vegetation Management and Other Legislation Amendment Bill" adopted in 2004.
[e] Based on the moratorium on clearing secondary vegetation imposed in 2009.
[f] Based on SLATS data period 1999 - 2005. Total cleared native and secondary vegetation 64300 ha.
[g] Percentage of the total cleared area.

The simulation results show that agents' participation in voluntary mechanisms was different between agent types and between scenarios (Table 5.2). In the baseline scenario, more than half of the agents with mixed, large crop and large mixed farms cleared secondary vegetation, while only a third of those with crop farms cleared it. On average, agents with large mixed farms cleared most of the land. In the broad protection scenario, less area was cleared than in the baseline scenario. At the same time, more than half of the agents with mixed and large mixed farms protected secondary vegetation, while only 20% of those with crop and large crop farms protected it. In the endangered ecosystems scenario, although fewer agents and hectares were cleared than in the baseline scenario, fewer agents with mixed and large mixed farms protected it than in the broad protection scenario. However, more agents with crop and mixed crop farms protected secondary vegetation than in the other two scenarios.

Table 5.2. Percentage of agents and average number of hectares cleared or protected per agent type in each scenario.

Agent type	**Baseline**		**Broad protection**				**Endangered ecosystems**			
	Cleared		Cleared		Protected		Cleared		Protected	
	%	ha	%	ha	%	ha	%	ha	%	ha
Crop farm	32	39	7	23	21	39	15	37	31	26
Mixed farm	58	49	9	43	61	63	22	49	42	33
Large crop	54	83	8	66	20	109	18	61	27	80
Large mixed	80	162	11	66	63	182	36	125	31	107

Differences between agents' decisions are reflected in changes in the amount of cleared and protected secondary vegetation for the whole region (Figure 5.2). While no secondary vegetation is protected in the baseline scenario, there is an increase of almost 30% and 10% of secondary vegetation cover for the broad protection and the endangered ecosystems scenarios respectively. Still, compared to the amount of secondary vegetation existing in 2007, almost a third is cleared in the baseline scenario, while less than 5% is cleared for the broad protection scenario by 2022. In the endangered ecosystem scenario, ecosystems of concern (<30% remaining) and endangered (<10% remaining) are better protected that in the other two scenarios, reflecting the implementation of voluntary mechanisms to restore this kind of ecosystems.

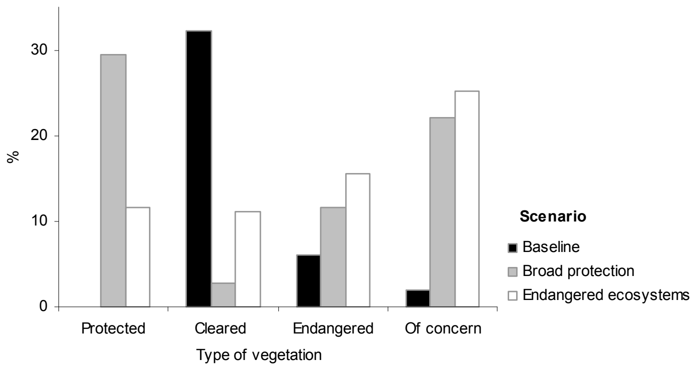
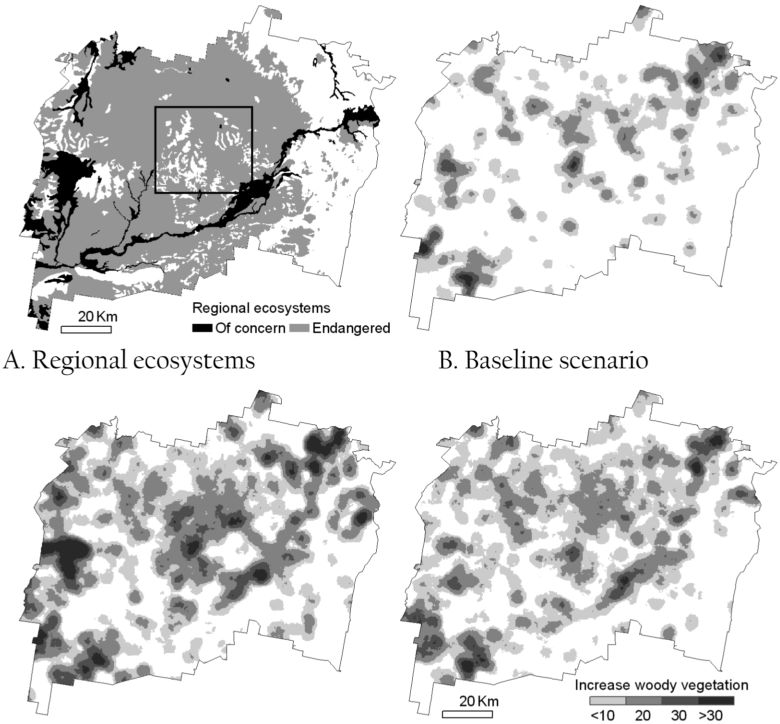


Figure 5.2. Comparison of changes over 15 years in the amount of woody vegetation and protected land between the different scenarios.



A. Regional ecosystems B. Baseline scenario

C. Broad protection scenario D. Endangered ecosystems scenario

Figure 5.3. Regional ecosystems and average number of pixels in the surrounding with an increase of woody vegetation by 2022 in the three different scenarios.

Changes in the amount of cleared or protected area with secondary vegetation would be different throughout the region. Figure 5.3 shows the relative increase of woody vegetation cover for the different scenarios. In the baseline scenario, there would be a small, patchy increase in secondary vegetation across the region. In the other two scenarios, a large increase of secondary vegetation would occur in the ecosystems classified as of concern, which in the region corresponds mainly to alluvial ecosystems. Changes in the broad protection scenario would be higher and cover more areas than in the endangered ecosystem scenario.

Finally, differences in agents' decisions and regional changes in the amount of cleared and protected area influence the landscape structure in the region (Figure 5.4). Changes in the landscape structure are not dramatic because most of the current structure is protected as remnant native vegetation. However, there is some reduction in the amount of secondary vegetation in non-protected areas under the baseline scenario, while the increase in alluvial ecosystems would be likely to occur in both broad protection and endangered scenarios. Still, more secondary vegetation is protected and less is cleared in the broad protection scenario than in the endangered scenario.

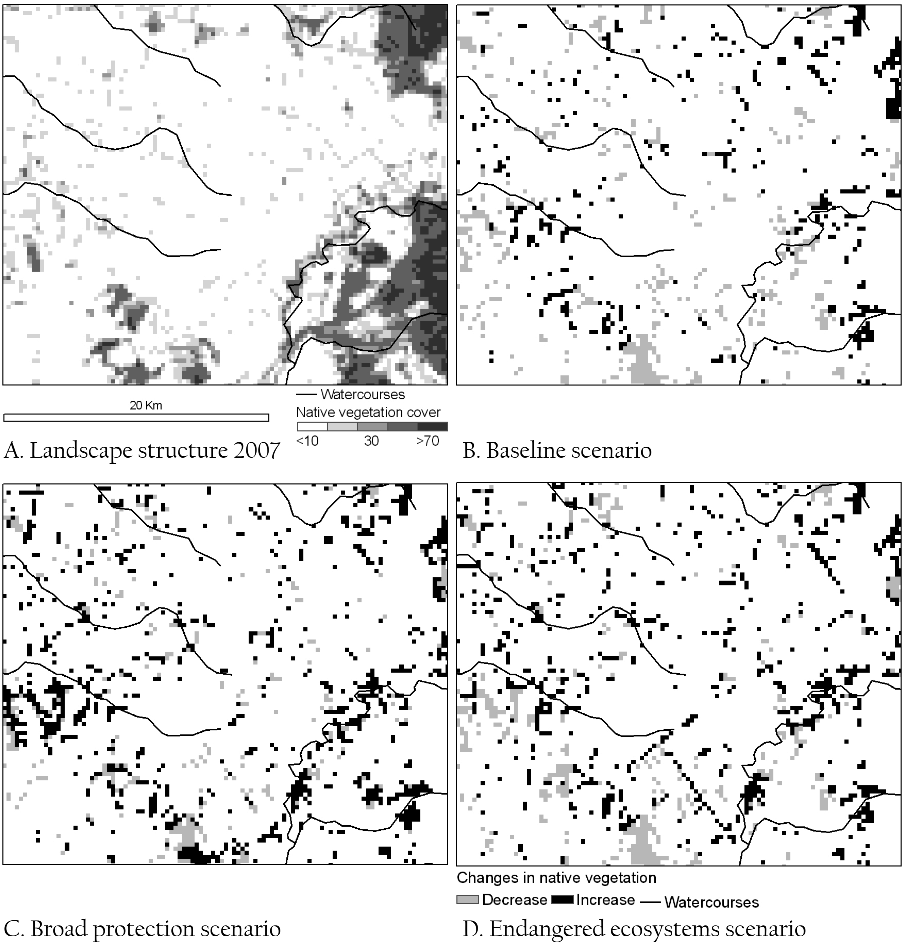


Figure 5.4. Cover (year 2007) and changes in native vegetation (year 2022) in the simulated scenarios in a subarea of the region (see Figure 5.3.A).

4 DISCUSSION AND CONCLUSIONS

This chapter demonstrates an approach to analyse and model how farmers' participation in voluntary mechanisms can affect the landscape structure in a rural region. The results of the semi-structured interviews list some barriers of farmers' participation in voluntary mechanisms, including lack of communication between farmers and government, lack of motivation of those farmers who are already protecting native vegetation with few or no incentives, need for economic compensation, differences in opportunity costs and underestimation of the value of native vegetation. These results support previous studies that identified barriers of participation in voluntary mechanisms, including characteristics of the farmer and the farm, and the mechanisms themselves (Pannell et al., 2006; Mendham et al., 2007).

The diversity in farmers' ability and willingness in the region confirms that the barriers of participation are not necessarily the same among farmers (e.g. Robinson, 2006). For the study area, part of this diversity includes the role of native vegetation in the production system and the opportunity costs of allowing secondary vegetation to grow back in agricultural areas. As the simulation results showed, the diversity in farmers' ability and willingness is especially relevant when voluntary mechanisms are aimed at restoring regional ecosystems classified as endangered and of concern. The simulation results also highlight how changes in farmers' willingness as a result of the implementation of voluntary mechanisms can affect the landscape structure of a rural region. While providing farmers with no incentives can lead to a landscape with less native vegetation, the implementation of voluntary mechanisms could increase the amount and distribution of native vegetation in the region.

4.1 Approach: limitations and strengths

In spite of the possibility offered by the approach to translate individual decision-making to regional spatial patterns, some limitations of the approach need to be discussed. This approach requires an understanding of farmers' willingness to participate in voluntary mechanisms in a spatial context. General knowledge about farmers willingness to participate in voluntary mechanisms is available (Wilson and Hart, 2000; Toogood et al., 2004; Brodt et al., 2006; Pannell et al., 2006; Sharpley and Vass, 2006; Mendham et al., 2007). However, to obtain these data for all farmers in a specific rural region and to link them to spatial processes is not often possible. Although additional empirical methods such as interviews, experiments and role-play games could help us to get a better insight in farmers' decision-making (Janssen and Ostrom, 2006; Robinson et al., 2007), it is still difficult to grasp what interacting factors influence farmers' decisions and how this influence can evolve over time for a whole region. Related to this lack of data and uncertainty about farmers' decision-making, this approach requires the use of different quantitative and qualitative data. All these aspects make the LUCC modelling an uncertain process, limiting the statistical validation of its results. Therefore, the application of simulation results depends on the specific context and description of the system (Verburg, 2006; Matthews et al., 2007).

Despite the difficulties of parameterising the model, the approach presented in this chapter offers several advantages. This approach explicitly takes into account farmers' response to changes in policies as a proximate cause of LUCC processes in rural regions. In this way, this approach can include key factors for the adoption of land-use policies such as farmers' willingness and diversity of decision-making, which are especially relevant to study the adoption of voluntary mechanisms. The capacity to include these two factors contrasts with most LUCC spatial models, which disregard farmers' willingness and assume that decision-making in rural regions is homogeneous among farmers (e.g.

Pijanowski et al., 2002; Verburg et al., 2002). In addition, this approach explicitly represents farmers' decisions in a spatial context, which requires us to combine different organisational and spatial levels of LUCC in rural regions (i.e. field, farm and region). The explicit combination of different spatial levels is often disregarded in LUCC models. Yet, to include this combination of organisational and spatial levels help us to understand better the interaction between human and environmental systems (O'Sullivan et al., 2006; Liu et al., 2007). Further, the use of a probabilistic approach to represent decision-making processes allow us to use both qualitative (i.e. interviews) and quantitative data (i.e. land-cover data and cadastral data). The use of qualitative data can give us a better understanding on how probabilities link to real processes, which according to Batty and Torrens (2001) is challenge of using probabilistic approaches in modelling. Finally, this approach makes use of simple and flexible tools such as interviews, agent typologies and probabilistic decision-making. This flexibility makes of it a generic approach that can be used to analyse and explore different voluntary mechanisms in different rural regions.

4.2 Implications for management and land-use policy

Current socio-economic and spatial processes in many rural regions in Australia, North America and Europe are partly driven by the increasing demand for non-agricultural goods and services in rural regions, including nature conservation, CO_2 storage and tourism accommodation. As many of the mechanisms implemented to meet this demand rely on voluntary participation (e.g. agri-environmental schemes, carbon credit schemes and rural tourism accommodation), the approach described in this chapter can be used as a basis for ex-ante tools to analyse and explore the effect of the implementation of voluntary mechanisms in LUCC processes in rural regions.

Specifically, the results of this chapter have some implications for management and land-use policies. By identifying the characteristics of the farmers, the farm and the mechanisms that can influence farmers' ability and willingness, we take a step towards the recognition of the potential barriers that can hamper farmers' participation in voluntary programmes. As Pannell et al. (2006) and Mendham et al. (2007) mention, taking these barriers into account in the design of voluntary mechanisms can increase the chances that farmers will participate in such mechanisms.

Further, the inherent diversity in farmers' ability and willingness to participate in voluntary mechanisms in the study area supports the findings of several authors who argue that to take account of this diversity in the design of these mechanisms can enhance farmers' participation (Schmitzberger et al., 2005; Brodt et al., 2006; Knowler and Bradshaw, 2007). Finally, the results of this chapter indicate that the design of voluntary mechanisms as well as the diversity among farmers results in unequal patterns of adoption across the landscape. In assessing alternative voluntary mechanisms and their effects on the spatial outcomes can also help to better design and target such mechanisms.

APPENDIX B. MODEL DESCRIPTION

The application of the modelling framework described in this chapter was done in NetLogo 4.1. A run of the model consisted in 15 time steps or years. Five main land-use types were defined (intensive used areas, crop land, extensive agriculture areas, nature areas and water bodies). Management of native vegetation was the only decision-making processes included in the simulation. Additionally, a process of secondary vegetation growth was defined. It was assumed that the remnant native vegetation in 2004 would not be cleared as a result of current policy regulations. Further, areas where native vegetation was cleared after 1990 cannot be included in any voluntary mechanism given the current set up of those schemes—specifically carbon credit schemes.

Each agent owned one or several fields, each field was formed by one or several pixels and a pixel represented 10 hectares. Agents' characteristics include agent type, owned farm, farm size, crop area, cover of native vegetation, memory (actions of the previous 5 years), location (distance to the main town) and probabilities for the decision-making process. The initial probability of each agent was established based on the available historical land-cover data. As some of these empirical data were gathered with a temporal scale of 2 or 3 years, they were re-scaled to 1 year. For each scenario, specific assumptions of agents' decision-making were defined consistent with the scenario description in the chapter. Table B gives an overview of these scenario specific assumptions. Pixel characteristics included field number, land-cover type, soil type, native vegetation cover, type of native vegetation (e.g. remnant or secondary vegetation), location within the field (border), distance to the nearest watercourse, probability that secondary vegetation will grow and memory (i.e. year that it was cleared).

Table B. Comparison of the different assumptions of decision-making between scenarios.

Assumptions	Scenarios		
	Baseline	Broad protection	Endangered ecosystems
Voluntary mechanisms	-	+	+
Protection remnant native vegetation	+	+	+
Protection of current secondary vegetation	+/-	+	+
Use of extensive land to protect native vegetation	-	+	+
Use of crop land to protect native vegetation	-	-	+

The model was set up with all the socio-economic and spatial characteristics of both agents and pixels. For each scenario, pixels that could be cleared or protected were selected. In the baseline scenario, areas with secondary vegetation that fell under the moratorium establish in 2009 were the only ones that could be protected. In this case, protection of secondary vegetation depended purely on agents' willingness. In the broad protection scenario, besides areas under moratorium, areas cleared before 1990, with extensive use and areas less suitable for agriculture (e.g. alluvial plains and sand plains) could be protected. In areas with extensive use, however, only those nearby watercourses (< 200 m) and those surrounding a field could be protected. In the endangered ecosystems scenario, only regional ecosystems of concern and endangered located in the same areas as the previous scenario could be protected. Additionally, crop land nearby watercourses and surrounding watercourses could also be protected.

In every time step, a process of secondary vegetation growth took place. Then, agents decided whether they will clear and/or protect secondary vegetation in their farms. Finally, the landscape was updated.

Secondary vegetation growth

Growth of secondary vegetation included three sub-processes. Firstly, secondary vegetation emerged as a random process (uniform distribution). This random process could take place either in areas under extensive agriculture use and cleared at least 5 years before or in areas protected by agents. Secondly, if a pixel (10 ha) was covered to some extent by secondary vegetation, this coverage would increase every year. Finally, secondary vegetation could disperse to neighbouring pixels that belonged to the same field.

Management of native vegetation

Agents could decide to clear a field when the foliage percentage cover of the secondary vegetation was higher than 5% in any of the pixels of that field. If the agent decided to protect part of the secondary vegetation, s/he would choose the areas selected for protection of native vegetation for each scenario. If there were none of such areas, s/he would clear the entire field. This means that although there was an influence of past decisions, agents' willingness to clear secondary vegetation did not directly depend on the willingness of the previous year (i.e. no path dependence). In contrast, decisions on whether to protect secondary vegetation were path dependent. To represent this dependence and keep certain coherence on their decisions, previous decisions and future options were linked. Agents' decisions were limited by drawing a random number out of a normal distribution. The amplitude of this distribution defined agents' options for a certain year, while the frequency distribution defined the most likely decision. The value of the mean of this distribution was the value of the previous decision, while the value amplitude or the standard deviation of the curve was calibrated with the model.

Decisions on clearing or protecting secondary vegetation depended on several factors such as agent type, previous actions and current land-cover. Agents with large mixed farms were more likely to clear secondary vegetation (52%; mixed farm 28%; crop farms 10%; and large crop farms 20%) and to protect regrowth (88%) than any other agent type (mixed farm 66%; crop farms 52%; and large crop farms 86%). The probability that agents would clear secondary vegetation depended also on the amount of cleared land in the previous 5 years—the more they have cleared the less likely to clear again. For the initial probability, this was calculated based on land-cover change data between 2001 and 2005. The probability that agents would protect secondary vegetation depended also on the amount of native vegetation in their farm—the more native vegetation in their farm, the less likely to protect secondary vegetation. The initial probability was calculated based on land-cover data of 2007.

Chapter 6

Synthesis: an agent-based approach for regional land-use research

1 AN ACTOR-BASED APPROACH

The focus of this dissertation was on implementing and applying an actor-based approach to analyse and explore LUCC as the response of farmers' decisions to endogenous and exogenous processes in rural regions. This implementation and application was based on three main research questions formulated in Chapter 1. In this Chapter, the questions are briefly answered and discussed. Finally, conclusions and further research options are considered.

1.1 How to characterise the diversity of farmers' decision-making within rural regions with respect to land-use change?

A generic method to characterise the diversity of farmers' decision-making within rural regions was demonstrated in Chapter 2. By formulating an agent typology, it was possible to identify, characterise and allocate empirically different decision-making strategies within a rural region. The empirical nature of the proposed method is a step towards the development of empirically-parameterised regional ABM. Still, the diversity of decision-making can be included in different ways depending on the modelling context.

The diversity of decision-making represents an endogenous process that influences LUCC of rural regions. To analyse such diversity, typologies have been implemented in rural studies for a long time (McKinney, 1950; Jollivet, 1965). The aim of using typologies in these studies is mainly to simplify and compare different farming strategies within a region (Escobar and Berdegué, 1990; Perrot and Landais, 1993a; van der Ploeg, 1994).

The use of typologies in ABM has become a common practice (e.g. Ziervogel et al., 2005; Happe et al., 2006; Acosta-Michlik and Espaldon, 2008; Becu et al., 2008; Le et al., 2008; Brady et al., 2009; Fontaine and Rounsevell, 2009; Freeman et al., 2009; Kaufmann et al., 2009). Agent typologies can be used in two interrelated ways. Similar to rural studies, agent typologies in land-use research can be used to simplify and investigate the (spatial) interaction between the diversity of decision-making and LUCC processes (Chapter 2; Valbuena et al., 2008). In other words, agent typologies are used to parameterise agents' behaviour (e.g. Acosta-Michlik and Espaldon, 2008; Le et al., 2008). For example, in Chapter 5 an agent typology is used to simplify and represent agents' decision-making. Additionally, agent typologies can be used as a mechanism to populate the ABM processes (Chapter 2; Valbuena et al., 2008). This is the case of ABM whose empirical parameterisation is based on a sample instead of the whole agent population—which is often the case of models with a regional extent. In these models, the use of agent typologies facilitate the up-scaling of agents' behaviour and/or attributes from the sample to the whole agent population (Smajgl et al., submitted). Up-scaling can be done by either creating new agents based on the characteristics of each agent type (e.g. Brady et al., 2009; Happe et al., 2009; Piorr et al., 2009) or classifying existent farms into the different agent types processes (Chapter 2; Valbuena et al., 2008).

Agent typologies are not the only mechanism to represent the diversity of decision-making in ABM. According to Smajgl et al. (submitted), this diversity can be included in four different ways depending on the modelling context (e.g. research question, spatial level and data availability). First, the entire diversity of decision-making can be included in the ABM by sampling the whole population. This is often the case of ABM designed to represent processes at local scales with a low number of decision-makers. Second, the diversity of decision-making can be integrated by using proportional up-scaling (e.g. cloning of agents), assuming that the sample population is representative for the whole agent population. Third, this diversity can be incorporated by means of a disproportional up-scaling (e.g. agent typologies). This up-scaling assumes that the sample of the population is not representative for the whole population and that it is necessary to include minority behavioural responses relevant for the LUCC processes. Finally, the diversity of decision-making can be included by down-scaling processes (e.g. Monte Carlo approaches). Down-scaling is done by the creation or parameterisation of agents' characteristics (e.g. ability and willingness) based on aggregated census data.

Independently of the implemented mechanism, to take account of the diversity of decision-making in ABM enhances the understanding and exploration of LUCC. In this way, LUCC is analysed as an emergent pattern caused by the diversity of decisions and interactions of the actors involved in LUCC.

1.2 How to represent and simulate changes in landscape structure in rural regions as a result of farmers' decision-making?

An actor-based approach was described to represent and simulate LUCC processes in rural regions as a response of farmers to socio-economic and biophysical processes (Chapter 3). This approach was implemented in an agent-based framework, which was built by combining different concepts and tools including farmers' willingness and ability, decision-making corridors, agent typologies and probabilistic decision-making. The description and implementation of the modelling framework made several contributions to land-use research. By using this framework, it was possible to simulate LUCC processes in rural regions by developing empirical ABM. Moreover, this framework explicitly linked farmers' decision-making and LUCC processes at field, farm and regional level. Finally, it is a generic framework that can be applied to different regions and to different LUCC processes.

To contextualise the applications of this agent-based framework, a short literature review of different ABM was carried out (see Appendix C). The intention of this review is to give an overview of how this study relates to other implementations and applications of ABM in land-use research.

The overview of current applications of ABM corroborate the statement of Matthews et al. (2007) that the application of ABM in land-use research is steadily increasing and broadening. Although a systematic comparison between models could provide the state-of-the-art of ABM, such a comparison is not a simple task as their design depends on many factors related to the research question, discipline(s) involved and availability of data (Parker et al., 2008). In ABM, for example, agents' decision-making can be defined as a social (e.g. social interactions and multi-actor decision-making), economic (e.g. utility functions and heuristics) or spatial process (e.g. historical land-cover changes). Also, ABM is used to analyse and simulate the interaction between humans and their environment including urban, urban-rural or rural processes. Further, ABM can be designed to comply with several tasks ranging from LUCC exploration, policies analysis, participation modelling, testing social science concepts and explaining land-use functions (Matthews et al., 2007). Additionally, ABM can be designed to simulate LUCC processes at local or regional levels. Finally, ABM can be developed alone, coupled with other models or integrated into meta-models.

As mentioned by Janssen and Ostrom (2006) and Robinson et al. (2007), the variability in the development of ABM and in data availability results in the parameterisation and calibration of ABM based on a blend of expert knowledge and empirical data. Additionally, these empirical data are gathered or available at different spatial and temporal levels (e.g. surveys, aggregated census data and historical land-cover data). The blend of datasets is reflected in different ways to represent agents' attributes and behaviour, and the landscape (Appendix C).

Until recently, few ABMs were: (i) empirically parameterised; (ii) used to model LUCC in regions; or (iii) designed to analyse spatially real-world policies (Parker et al., 2003; Berger and Schreinemachers, 2006; Matthews et al., 2007). Therefore, the main methodological innovation of this dissertation is to propose and demonstrate an agent-based framework that covered these three aspects. This methodological innovation has already been discussed in Chapter 3, 4 and 5. Nevertheless, other ABM applications have recently covered these methodological aspects too. For example, the development and application of AgriPoliS (Happe et al., 2006; Brady et al., 2009; Happe et al., 2009) and its link with other modelling techniques (Piorr et al., 2009) have represented a major step towards the development of empirical ABM to analyse policies in rural regions in Europe. In AgriPoliS, agents correspond to individual farms and agents' decision-making is represented as a profit maximisation strategy (Happe et al., 2006). This ABM has been specifically used to analyse the impact of policy scenarios on: (i) structural change, including farm size, economic land rent and profit (Happe et al., 2006); (ii) the dynamics of single-holder and corporate farms, including number of farms, farm size and land rental prices (Happe et al., 2009); (iii) farm structure, land-use change (e.g. land abandonment and changing in cropping systems) and environmental processes such as soil and water erosion (Piorr et al., 2009); and (iv) farm structure, land-use change and biodiversity (Brady et al., 2009). Another example is the ABM applied by Kaufmann et al. (2009), who develop a agent decision-making framework based on social psychology. This framework is applied to analyse how advisors and subsidies can influence the adoption of organic agriculture in rural regions of 3 New EU Member States. Freeman et al. (2009) describe an economic ABM to simulate past structural change. In this study, policy scenarios were used to understand how past policies could have influenced structural change in a Canadian rural region. In contrast to these examples of rural LUCC, Fontaine and Rounsevell (2009) describe HI-LIFE, a regional ABM to simulate urban development as the result heterogeneous household agents. HI-LIFE is spatially explicit model that was empirically parameterised for a region in UK.

Several similarities and differences can be distinguished between the ABM applications described in this dissertation and these regional ABM examples. The main similarity is that all of them are regional models, empirically parameterised and used to analyse policies. Furthermore, there is the need to represent and include the heterogeneity of agents' attributes and/or behaviour within the region in all these ABM applications (see Section 1.1). This heterogeneity can be captured by selecting agent types based on expert knowledge (Fontaine and Rounsevell, 2009; Freeman et al., 2009; Happe et al., 2009) or quantitative analyses (Happe et al., 2006; Brady et al., 2009; Kaufmann et al., 2009; Piorr et al., 2009). Another similarity is the need to use virtual representations or stochastic processes to parameterise part of the model due to lack of data. Additionally, none of these ABM explicitly represents agents as entities able to adapt to changing conditions or able to learn from previous experiences or from social interactions. One more similarity is the poor or no representation of social networks and institutions. Only Happe et al. (2006) integrate a land market in the ABM and Kaufmann et al. (2009) include the influence of social networks on agents' decisions.

Similarities between these applications of ABM are largely related to the regional extent at which these models are developed. At this extent, it is not possible to gather and manipulate all the information related to LUCC processes. Therefore, it is impossible to capture the complexity of land-use processes of a specific rural regions fully (Happe et al., 2006). In fact, adding too much information can cause that any ABM becomes too complicated to understand. Therefore, the use of such models should be better focussed on a subset of the real world (Parker et al., 2008).

Differences between the examples mentioned above and the applications of the agent-based framework described in this dissertation are mainly conceptual. The first difference is the representation of agents' decision-making. While in most of the examples decision-making is based on maximisation functions, Kaufmann et al. (2009) also describe a regional ABM that explicitly includes farmers' willingness (i.e. motivation) to take land-use decisions. To include farmers' willingness in ABM is especially relevant when looking at farmers' participation in voluntary mechanisms such as agri-environmental schemes (Chapter 2 and 4).

A second difference is the link between agents' decisions and changes in the spatial configuration of the landscape. As most of the ABM examples aim at simulating the effect of policies on structural change in rural regions, they do not attempt to translate those changes in the spatial structure of the landscape. Although Brady et al. (2009) bridge the gap between changes in farm structure and regional land-use changes, this bridge is related to changes in the land-use pattern of the whole region, instead that changes in the density and location of landscape elements (see Chapter 4 and 5).

Another difference is that most examples use maximisation functions calculated based on structural characteristics of the farm including labour, income and costs of running the farm (e.g. Happe et al., 2006; Brady et al., 2009; Happe et al., 2009). In contrast, Kaufmann et al. (2009) describes a probabilistic approach similar to the one described in Chapter 3 (Valbuena et al., 2010). With these probabilistic approaches, it is possible to quantify and include the effect of endogenous and exogenous factors (e.g. social networks or policy changes) on farmers' ability and willingness to take certain decisions. Thus, the main advantage of these probabilistic approaches is their flexibility and facility to be parameterised with empirical data, to mimic processes at a farm level and to simulate the emergent pattern for the whole region (e.g. diffusion of organic farming or changes in the landscape structure). The drawback of such flexibility is that probabilistic approaches cannot explain the underlying processes. In particular, the probabilistic approach described in Chapter 3 can mimic how the response of changes in policy can influence farmers' decisions. Although this probabilistic approach cannot be used to understand how such an influence takes place, it helps to understand how the variation in decision-making can lead to emergent LUCC patterns, taking into account non-linear interactions and path dependence. Related to this, as people's response to socio-economic and biophysical processes drive LUCC processes (Lambin et al., 2001), an ABM using probabilistic approaches can explain better LUCC processes than aggregated-level modelling techniques (Chapter 4). Furthermore, as shown in Chapter 4 and 5 (Valbuena et al., in press; Valbuena et al., in review), the use of qualitative data (e.g. expert knowledge and semi-structured interviews) can improve the understanding, as well as decrease the uncertainty attached to probabilistic approaches.

1.3 How to apply this knowledge to explore the effect of land-use policies on the landscape structure in different study areas?

The agent-based framework was applied to two different rural regions. For both regions, the parameterisation and verification of the internal properties of the ABM were carried out by combining both qualitative and quantitative data.

In the Dutch rural region, the agent-based framework was applied to analyse and explore how farmers' response to changes in global and national socio-economic process and policies can influence the landscape (Chapter 4). To achieve this, expert knowledge, a sample survey, cadastral maps and census data for two different periods were used to characterise different agent types, as well as to allocate these types for the whole region. Further, the simulation of different scenarios combined with the results of an economic model for the whole country was used to represent the influence of exogenous processes on farmers' decision-making. Also, land-cover data were use to analyse spatial structure of the landscape in the region. Additionally, statistical analysis and expert knowledge were used to verify some steps of the modelling processes. Finally, the results described the interaction between land-use policies, the diversity of decision-making, changes in the farm structure of the region and changes in the landscape structure.

In the Australian rural region, the agent-based framework was applied to analyse and explore how farmers' participation in voluntary mechanisms to restore native vegetation can influence the landscape structure of the region (Chapter 5). For this region, there was less data available—specifically on farmers' willingness (i.e. sample survey). Therefore, cadastral and land-cover data were mainly used to characterise the different agent types of the region, as well as to allocate these types for the whole region. To counterbalance the lack of data, historical land-cover data combined with qualitative data (i.e. interviews) were used to understand better farmers' decision-making in the region. Related to this, scenarios that linked the adoption of voluntary mechanisms and farmers' willingness were described and simulated. In addition, statistical analyses were carried out to verify the identified agent types. Finally, the results described the interaction between land-use policies, the diversity of decision-making and changes in the landscape.

The applications of the framework mentioned above show that one of the main challenges in ABM is the validation of the modelling results. According to Parker et al. (2003), the utility of ABM depends on the validity and verification of the modelling results. Validation of modelling results is essential to provide credibility when the results are used in a policy context (Pontius et al., 2008). Different verification and validation processes were carried out in the regional applications of ABM described in Section 1.2. For example, instead of validating the results, Happe et al. (2006) carry out sensitivity analyses to consider the model assumptions and the interaction between parts of the model in order to analyse the modelling results. Fontaine and Rounsevell (2009) compare the correlation coefficients of the observed and simulated spatial distribution of households in order to analyse the effects of model calibration. Freeman et al. (2009) simulate a base scenario to validate the model results. In this dissertation, we used expert knowledge to validate the plausibility of the modelling results (Chapter 4).

Nevertheless, validation of individual decision-making processes is not feasible due to their uncertainty and lack of available data (Messina et al., 2008). In fact, agent's behaviour is a simplification of the theory from which the model derives (Moretti, 2002). This means that besides the internal validation of the model (Axelrod, 1997), ABM should be better validated at a more aggregate level such as population structure or spatial patterns (Brown et al., 2005). Still, more than one model construction can generate the same structure or patterns, which becomes even more problematic when the modelling outcome is used in policy-making (Oreskes et al., 1994). This results in two main implications for ABM in land-use research. The first implication is related to the use of ABM in land-use research. As Box and Draper (1987) state, all models are wrong but some of them are useful. In fact, the level of data required to parameterise ABM and the uncertainty attached to past, current and future human decision-making, and social and environmental systems restrict the predictive capacity of ABM (Lempert, 2002; Verburg, 2006). This supports the statement of Matthews (2007) and the conclusion of Chapter 4 and 5 that ABM are tools that should be only used to understand and explore LUCC processes, not to predict them.

In policy-making, ABM as any other modelling tools can be used to: (i) understand complex LUCC processes; (ii) create and compare alternative scenarios; and (iii) facilitate the participation and discussion between stakeholders (Fabos, 1988; Klosterman, 1997; Uran and Janssen, 2003). Specifically, as ABM makes it possible to include human behaviour in simulations, their use in planning and policy-making has raised many expectations (Ligtenberg et al., 2001; Gimblett, 2002; Sengupta et al., 2005). Although the aim of this dissertation was not to develop a planning tool, the described agent-based framework can be considered as a basis for such a tool. The main advantage of this agent-based framework is its flexibility to be used in different regions and different LUCC processes, while being simple to understand and parameterised. In general, planners are reluctant to use complicated quantitative tools (Geertman and Stillwell, 2003). Also by using this agent-based framework, uncertainty can be easily calculated and visualised, which can improve the link between science and policy-making processes (Bradshaw and Borchers, 2000). Still, future application of the agent-based framework should include policy-makers and other stakeholders. In fact, the lack of communication between developers and users hampers the use of modelling techniques in planning and policy-making processes (Uran and Janssen, 2003; McIntosh et al., 2007).

The second implication for ABM in land-use research is related to the internal validation of the model. As the use of ABM should not aim at predicting LUCC processes, the use of traditional statistical methods (e.g. Pontius et al., 2008) may not be adequate to validate ABM results. Still, for those models whose results are spatially explicit (e.g. land-use or landscape patterns), validation may be possible by comparing simulated results and past or current patters (Brown et al., 2005). Equally or even more relevant is the verification of the internal properties of the model. Lempert (2002) suggests the use of ABM and multi-scenario simulations to test not the validity of the results but their robustness, resilience and stability. Grimm et al. (2005) introduce the pattern-oriented model to calibrate ABM. Thus, instead of using only a pattern to design an ABM (e.g. spatial, socio-economic or population structure), researchers should use multiple patterns at different spatial levels to design more robust models and decrease the uncertainty of LUCC processes. Related to this, Messina et al. (2008) emphasise the need to measure and include error and uncertainty in ABM results. For probabilistic ABM, the use of statistical analysis can be carried out to control the bias, noisy and collinearity in such models (Santner et al., 2003). With the agent-based framework described in Chapter 2, uncertainty can be easily represented, showing the robustness of the modelling results. Nevertheless, further applications of this modelling framework should include more structured comparisons of the modelling results with past and current socio-economic and spatial patterns.

The application of the agent-based framework makes it possible to compare LUCC in different rural regions. LUCC is a multi-level process in which different biophysical and socio-economic actors and factors interact at different organisational, temporal and spatial levels (Aspinall, 2008). The applications of the agent-based framework described in this dissertation illustrate such interaction. In the case of the Netherlands, the continuation of economic support to the agricultural sector, including bottom-up programmes such as LEADER+, can persuade farmers to protect landscape elements. This can enhance the interconnection between agriculture and nature, reinforcing the cultural and natural identity of the region (Chapter 4). Other studies have demonstrated the influence of exogenous processes on the cultural identity of other rural regions. In some Mediterranean regions, for example, economic support represent an important mechanism in the economic viability of farms with traditional agricultural systems (Duarte et al., 2008). Also, future changes in socio-economic processes (e.g. market and policy regulations) can influence processes of land abandonment, nature development and urbanisation in Europe, affecting the cultural and natural value of the landscape (Verburg et al., 2006).

In contrast, the continuation of top-down policy restrictions in Australia—without reinforcing bottom-up approaches such Landcare groups—limits farmers' willingness and ability to protect native vegetation. Consequently, this lack of support can lead to a further decline of native vegetation throughout the region (Chapter 5). Similar degradation processes of native vegetation have been described for other regions. In some regions of Brazil, for example, vast areas of tropical forests have been cleared as the result of the increasing global demand for soya beans, infrastructure development to promote soya plantations, economic governmental support to develop this agricultural sector and lack of policies to protect native vegetation (Fearnside, 2001). Also in Malaysia, the clearing of vast areas of native vegetation was caused by the lack of effective measures to protect and to restore native vegetation, commercial logging and the expansion of export-oriented plantations supported by both public and private investment (Barraclough and Ghimire, 2000).

The applications of this agent-based framework help to analyse part the interactions between actors and factors at different organisation and spatial levels. The results of these applications also facilitate the comparison of LUCC processes between rural regions and the understanding of LUCC processes as the result of the interactions between endogenous and exogenous processes.

2 CONCLUSIONS AND FURTHER RESEARCH

The development of ABM has largely facilitated the use of actor-based approaches in land-use research. This dissertation demonstrates an actor-based approach to explore LUCC in rural regions as the response of individual decision-making to endogenous and exogenous processes. The implementation and application of this approach make several conceptual and methodological contributions to land-use research.

The main contribution of implementing and applying this actor-oriented approach is to combine explicitly different organisational and spatial levels. Compared to aggregated-level approaches, this actor-based approach can be used to explain LUCC in rural regions as the result of the response of the diversity of decision-making to endogenous and exogenous processes. To include explicitly these different level improves our understanding of the interactions between human-environmental systems (O'Sullivan et al., 2006; Liu et al., 2007). Specifically, to include these different levels helps to include and understand the non-linearity and path dependence of LUCC processes.

Still, the combination of actor-based and aggregated-level approaches can give a better insight in LUCC processes in rural regions. For example, Castella et al. (2007) use different actor-based and aggregated-level modelling techniques in a case study in Vietnam. The authors conclude that the use of these methodologies is complementary in terms of land-use research and policy formulation. In this dissertation, for example, aggregated-level approaches could be implemented to analyse how the response of farmers to policy regulation can change the landscape, including its provision of goods and services. According to Willemen et al. (2008) the provision of such goods and services need to be analysed at a regional and not only at a farm level (e.g. recreation and water supply). Thus, instead of looking at actor-based and aggregated-level as competing research approaches and tools, they should be combined to understand better the complexity of LUCC processes.

Other methodological contributions of the implementation and application of this actor-based approach are: (i) the development a generic approach that can be applied to different regions and different LUCC processes (ii) the incorporation of the diversity of decision-making of rural regions; (iii) the link between individual decision-making and changes in the spatial patterns of the landscape; (iv) the empirical parameterisation of ABM; and (v) the development of an ABM to policy analysis at a regional level. These methodological contributions are also related to the combination of concepts and methods of different disciplines. In fact, LUCC is the result and the driver of social and environmental processes, and therefore, it represents a common research ground for both social and natural sciences. In this dissertation methods and concepts of different disciplines are used. For example, farm typologies (McKinney, 1950; Jollivet, 1965) and the concepts of farmers' willingness and ability (Siebert et al., 2006) have been used in Rural Sociology. Some of the elements of agents options, decisions and actions were adapted from Social Psychology (Ajzen, 1991). The probabilistic approach to represent individual decision-making was used based on farm trajectories developed in Human Geography (Wilson, 2007). This means that to keep its conceptual and methodological richness, land-use research should offer a common ground for the interaction of different disciplines and stakeholders, instead of becoming a science in itself as suggested by some authors (Rindfuss et al., 2004; Turner et al., 2007).

However, further research challenges in the application of this actor-based approach still remain. First, the LUCC processes represented in this dissertation did not include changes in the agricultural use of the land (e.g. intensification, crop/pasture and crop changes) or other LUCC process (e.g. urbanisation), which can also be affected by policy regulations. Further research should include some of these processes to understand better LUCC processes in rural regions. Second, the applications presented in this dissertation did not explicitly include the interactions between farmers or the influence of other regional actors on farmers' decisions (i.e. social networks). Although the representation and quantification of these interactions within rural regions is difficult, these social interactions can influence farmers' decision-making. Thus, further research should represent and include some of these social interactions. Third, despite the verification and validation steps carried out in Chapters 2, 4 and 5, future applications of this agent-based framework should include more structured comparisons of the modelling results with past and current socio-economic and spatial patterns. Fourth, further research need to include the temporal dynamics of human decision-making and LUCC processes. Fifth, as it was illustrated in Chapter 4, further applications of this framework should improve stakeholder participation in order to reduce the uncertainty of human decision-making and LUCC process. Finally, further research needs to take a step further by communicating or using these modelling techniques in real policy-making processes in order to test their real potential in policy analysis. In fact, modelling can be used to improve the communication between different stakeholders.

Despite these challenges, this dissertation represents a conceptual and methodological step towards the analysis and understanding of regional LUCC processes as the result of the interaction of different biophysical and socio-economic actors and factors that occur and interact at different organisational, spatial and temporal levels. This dissertation also supports the statement of Lambin et al. (2001) that although global forces (i.e. exogenous processes) have become the main determinant of LUCC, their impact in different regions can vary as these forces are mediated by institutional factors (e.g. market and policies) and as they can amplify or attenuate endogenous processes.

APPENDIX C. SUMMARY LITERATURE REVIEW OF ABM

Characteristics of the different ABM included in the literature review.

Country	Decision-making	Rural / Urban	Model use	Model level	Type of model[a]	Agent attributes	Agent behaviour	Landscape represent[b]	Published article
Philippines	Socio-economic	Rural	LUCC exploration	Local	ABM	Empirical	Empirical	Real-world	Acosta-Michlik and Espaldon (2008)
Thailand	Social	Rural	Participation modelling	Local	Coupled	Expert knowledge	Empirical	Real-world	Becu et al. (2008)
EU	Economic	Rural	Policy analysis	Regional	ABM	Empirical	Empirical	Virtual	Brady et al. (2009)
Brazil	Socio-economic	Rural	LUCC exploration	Local	ABM	Empirical	Empirical	Virtual	Deadman et al. (2004)
Thailand	Socio-economic	Urban-rural	LUCC exploration & testing social concepts	Regional	ABM	Empirical	Empirical	Virtual	Entwisle et al. (2008)
USA	Economic	Rural	LUCC exploration	Regional	ABM	Empirical	Empirical	Real-world	Evans and Kelly (2004; 2008)
UK	Social & spatial	Urban	LUCC exploration	Regional	ABM	Empirical	Empirical	Real-world	Fontaine and Rounsevell (2009)
Canada	Economic	Rural	LUCC exploration & policy analysis	Regional	ABM	Empirical	Expert knowledge	-	Freeman et al. (2009)
Germany	Economic	Rural	Policy analysis	Regional	ABM	Empirical	Empirical	Virtual	Happe et al. (2006)
Slovakia	Economic	Rural	Policy analysis	Regional	ABM	Empirical	Empirical	Virtual	Happe et al. (2009)
Vietnam	Socio-economic	Rural	LUCC exploration	Local	ABM	Empirical	Empirical	Real-world	Jepsen et al. (2006)
EU	Social	Rural	Policy analysis & testing social concepts	Regional	ABM	Empirical	Empirical	-	Kaufmann et al. (2009)

Vietnam	Socio-economic	Rural	LUCC exploration & policy analysis	Local	Coupled	Empirical	Empirical	Real-world	Le et al. (2008); Le (2005)
USA	Socio-economic	Urban	Policy analysis	Local	Integrated	Empirical	Empirical	Real-world	Ligmann-Zielinska and Jankowski (2007)
The Netherlands	Social	Urban-rural	LUCC exploration & policy analysis	Regional	ABM	Expert knowledge	Expert knowledge	Real-world	Ligtenberg et al. (2001; 2004)
Mexico	Socio-economic	Rural	LUCC exploration & testing social concepts	Regional	Integrated	Empirical	Empirical	Real-world	Manson (2005; 2006)
Nepal	Socio-economic	Rural	Explaining land-use functions	Local	Integrated	Expert knowledge	Expert knowledge	Real-world	Matthews (2006)
Brazil	Socio-economic	Rural	LUCC exploration	Regional	Integrated	Expert knowledge	Expert knowledge	Real-world	Moreira et al. (2009)
EU	Economic	Rural	Policy analysis	Regional	Integrated	Empirical	Empirical	Real-world	Piorr et al. (2009)
USA	Spatial	Urban-rural	LUCC exploration	Local	ABM	Expert knowledge	Empirical	Real-world	Robinson and Brown (2009)
The Netherlands	Social	Rural	Policy analysis	Regional	ABM	Empirical	Empirical	Real-world	Chapter 4
Australia	Social & spatial	Rural	Policy analysis	Regional	ABM	Empirical	Empirical	Real-world	Chapter 5
Lesotho	Socio-economic	Rural	LUCC exploration	Local	ABM	Empirical	Empirical	-	Ziervogel et al. (2005)

[a] *ABM* single models; C*oupled* with other models; and *Integrated* into meta-models

[b] *Real-world* = based on real landscape patterns; *Virtual* = based on aggregated data; - = not included

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Summary

Land use/cover change (LUCC) is the result and the driver of social and environmental processes, representing a common research ground for both social and natural sciences. Therefore, LUCC can be investigated using different approaches—specifically land-use research can be approached by looking at either the spatial units (often pixels) or the actors (often individuals and institutions). Pixel-based approaches look at LUCC as the aggregated result of socio-economic and biophysical processes (e.g. population dynamics and accessibility). Actor-based approaches look at LUCC as the response of different decision-makers to those processes. Each approach offers specific advantages and can be used to answer different questions. While pixel-based approaches are used to analyse LUCC at regional, national and global levels, actor-based approaches are often used to analyse LUCC at local levels. Availability of detailed socio-economic and biophysical data can facilitate the development of actor-based approaches to analyse LUCC in regions. Thus, this dissertation focuses on implementing an actor-based approach to explore LUCC in regions—specifically in rural regions.

Land-use research can be supported by using modelling techniques, which allow simplifying and simulating LUCC. For actor-based approaches, agent-based modelling (ABM) is commonly used. ABM is a technique to simplify and represent different decision-makers and their interactions with their environment. Because of these characteristics, ABM is used as a modelling technique in this dissertation. Still, there are several conceptual and methodological limitations in the implementation and application of ABM in rural regions including: the empirical parameterisation of the model, the design of regional models, the characterisation of the diversity of decisions and the link between human decisions and the spatial heterogeneity of the environment. The aim of this dissertation is twofold. The first part aims at developing methods to take account of individual decision-making related to LUCC and the emerging spatial structure of the landscape. The second part aims at using these methods to include the diversity of individual decision-making in the analysis of different (land-use) policies in rural regions. To achieve these objectives several conceptual and methodological challenges need to be addressed: (i) to characterise the diversity of farmers' decisions in rural regions; (ii) to represent and simulate changes in landscape structure in rural regions as a result of farmers' decision-making; and (iii) to apply this knowledge to analyse land-use policies in different rural regions.

A generic method to simplify and include the diversity of farmers' decisions was proposed based on the use of an agent typology. By combining different empirical methods to formulate this typology, it was possible to identify, characterise and allocate different decision-making strategies within a rural region. Although similar empirical methods have been long described to characterise the diversity of farmers' decision-making, the link of this diversity and the spatial heterogeneity of the landscape was one of the main achievements of this method. The empirical nature of the proposed method is a step

towards the development of empirically-parameterised regional ABM. Further, the uncertainty in the identification and allocation of the different decision-making strategies was an explicit result. However, several challenges still need to be met. Differences between characteristics and decision-making in rural regions are gradual rather than abrupt. Also, the characterisation of farmers' decision-making in rural regions based on empirical data is often limited to past or current situations. Finally, the characterisation and allocation of different decision-making strategies within regions requires large datasets.

An actor-based approach was described to represent and simulate LUCC processes as a response of farmers to socio-economic and biophysical processes. This approach was implemented in an agent-based framework, which was built by combining different concepts and tools including farmers' willingness and ability, decision-making corridors, agent typologies and probabilistic decision-making. The description and implementation of the modelling framework made several contributions to land-use research. By using this framework, it was possible to simulate LUCC processes in rural regions by developing an empirical ABM. Moreover, this framework explicitly linked farmers' decision-making and LUCC processes at field, farm and regional level. Finally, it is a generic framework that can be applied to different regions and different LUCC processes. Nevertheless, the implementation and application of this modelling framework still faces several challenges. As a result of the complexity and lack of data, decision-making processes in rural regions are difficult to understand completely and impossible to predict, limiting the statistical validation of the results of ABM. Additionally, the probabilistic approach used in this framework is a robust way to represent and simulate decision-making, but the meaning of such probabilities is often unknown. Finally, it is necessary to take account of the influence and interaction of farmers with other farmers, policy-makers and regional advisors in order to understand better farmers' decisions.

The agent-based framework was applied to explore LUCC processes in a rural region in the Netherlands. With this application, it was possible to link future socio-economic scenarios, farmers' decisions and changes in the landscape structure. The ABM was parameterised using a sample survey, census data, cadastral data and land-use/cover maps. The modelling results show how the continuation or reinforcement of the current policies can improve the interconnection between nature and agriculture by further developing nature and managing the landscape. In contrast, revoking these policies and favouring the liberalisation of agriculture would deepen the process of polarisation between nature and agriculture, causing a loss of cultural and natural values in the region. Although the dynamics of the landscape patterns of the region do not totally depend on farmers' actions, different decision-making strategies can affect differently the landscape structure. While some strategies can have an active role in changing the landscape, others can be more passive. This reinforces the added value of including the diversity of farmers' decision-making in regional land-use research. This application also emphasises how participation of stakeholders can reduce the uncertainty of the modelling processes.

The agent-based framework was also applied to a rural region in Australia to explore LUCC as a result of the adoption of voluntary mechanisms. With this application, it was possible to link farmers' participation in voluntary mechanisms to restore native vegetation with changes in the landscape structure. To parameterise the model, semi-structured interviews, cadastral data and historical land-cover maps were used. The results of the interviews identify some barriers of farmers' participation in voluntary mechanisms. The modelling results show how farmers' willingness and ability to participate in voluntary mechanisms can play a key role in the restoration of native vegetation in the region, specifically in the restoration of endangered ecosystems. These results also highlight how changes in farmers' willingness as a result of their participation in voluntary mechanisms can increase or reduce the amount of native vegetation, as well as its spatial distribution. This application demonstrate that the use of qualitative data can improve the understanding of probabilistic approaches to represent decision-making, as well as to get a better insight into farmers' willingness and ability to participate in voluntary mechanisms. Moreover, the application of this framework emphasizes the relevance of including the diversity of farmers' decisions not only in investigating LUCC processes, but also in the design of voluntary mechanisms.

To contextualise the applications of the actor-based approach described in this dissertation, a comparison with other regional ABM was carried out. It is concluded that the approach presented in this dissertation represents LUCC changes as a multi-level process, in which non-linearity and path dependence take place. Also, the application of this actor-based approach shows the added value of including individual decision-making in the understanding of LUCC processes at a regional level. Specifically, how individual farmers can respond differently to changes in policy, and how such responses can have spatial consequences in the structure of the landscape. Still, several challenges in the application of this approach remain. These challenges relate to: the representation of other LUCC processes (e.g. urbanisation), the representation of social-networks, model validation, temporal dynamics of LUCC processes, stakeholders' participation and use of ABM in policy-making processes. Despite these challenges, this dissertation represents a conceptual and methodological step towards the analysis and understanding of regional LUCC processes as the result of the interaction of different biophysical and socio-economic actors and factors that occur and interact at different organisational, spatial and temporal levels.

Sammenvatting

Veranderingen in het landgebruik en landbedekking zijn zowel de oorzaak als het resultaat van sociale en omgevingsprocessen en vormen daarmee een gezamenlijke onderzoeksbasis voor zowel de sociale als de natuurwetenschappen. Landgebruiksveranderingen kunnen dus worden onderzocht vanuit verschillende benaderingswijzen: door te kijken naar ruimtelijke eenheden (vaak pixels), of actoren (vaak individuen of instituties). Benaderingswijzen die zijn gebaseerd op een pixelmatige aanpak bekijken landgebruiksveranderingen als de optelsom van socio-economische en biofysische processen (bijvoorbeeld bevolkingsdemografie en erosie). Studies die landgebruiksveranderingen bestuderen vanuit actoren, beschouwen deze veranderingen als het resultaat van een serie menselijke beslissingen. Elk van deze benaderingswijze heeft echter een aantal voordelen wat ze geschikt maakt voor het beantwoorden van verschillende vragen. Terwijl de pixelmatige aanpakken vooral worden ingezet op de regionale, nationale en mondiale schaal, worden de actorgerichte benaderingen juist vaak gebruikt voor de analyse van landgebruiksveranderingen op lokale schaal. De beschikbaarheid van sociaal-economische en natuurwetenschappelijke data over actoren, vaak op bedrijfsniveau, is van doorslaggevend belang voor actorgerichte benaderingen die tot doel hebben landgebruiksveranderingen op de regionale schaal te analyseren. Dit proefschrift richt zich op de implementatie van een actorgerichte benadering voor het onderzoek naar landgebruiksverandering in regio's en meer specifiek in rurale regio's.

Landgebruiksonderzoek kan worden ondersteund door het gebruik van modelleertechnieken die landgebruiksveranderingsprocessen analyseren en simuleren. Voor actorgerichte benaderingen worden hiervoor vaak 'agent-based' modellen (ABM) gebruikt. *Agent-based modelling* is een techniek waarmee verschillende besluitmakers en hun interacties met de omgeving gemodelleerd kunnen worden. Het is vanwege deze eigenschap dat ABM's zijn gekozen als modelleertechniek in dit proefschrift. Er zijn niettemin meerdere conceptuele en methodologische beperkingen voor de toepassing en implementatie van ABM's in rurale regio's, voorbeelden zijn: de empirische parametrisatie van het model, het ontwerpen van ABM's op regionaal niveau, de grote diversiteit in beslissingstypen en het verband tussen menselijke beslissingen en de ruimtelijke heterogeniteit van de omgeving. Het doel van dit proefschrift is daarom tweeledig. In het eerste deel worden methoden ontwikkeld die individuele beslissingen over landgebruiksveranderingen koppelen aan de emergente (?) ruimtelijke structuur van het landschap. Het tweede deel tracht deze methoden te gebruiken voor de analyse van verschillende beleidsplannen gericht op landgebruik in rurale regio's, rekening houdend met deze diversiteit in beslissingen die boeren nemen. Om deze doelen te bereiken dienen de volgende conceptuele en methodologische uitdagingen te worden geadresseerd: (i) het bepalen van de verschillende typen van beslissingen van boeren in rurale regio's; (ii) het vormgeven en simuleren van veranderingen in de landschapsstructuur in rurale regio's die het resultaat zijn van boerenbeslissingen, en (iii) het toepassen van deze kennis door het landgebruiksbeleid van verschillende regio's te analyseren.

Hetuitgangspunt van een typologie van verschillende '*agents*', was het vereenvoudigen en hanteerbaar maken van de complexe diversiteit van besluitvormingsprocessen. Hierbij is gebruik gemaakt van een combinatie van verschillende empirische methoden die het mogelijk maakte om de verschillende beslissingsstrategieën te identificeren, karakteriseren en te plaatsen binnen een rurale regio. Hoewel eenzelfde soort empirische methoden al eerder zijn gebruikt om verschillende besluiten te typeren, is deze diversiteit nooit eerder gerelateerd aan de ruimtelijke heterogeniteit van het landschap en dat is een van de belangrijkste resultaten van deze methode. De empirische aard van de voorgestelde methode was ook een eerste stap in de richting van de verdere empirische parametrisatie van een regionaal 'agent-based' model. Ook, omdat in de uitkomsten expliciet rekening gehouden werd met de statistische betrouwbaarheid in de identificatie en allocatie van de verschillende beslissingsstrategieën. Er zijn echter nog steeds verschillende uitdagingen om deze methode te verbeteren. De verschillen tussen de karakteristieken van verschillende boeren bij het maken van beslissingen in rurale regio's zijn eerder gradueel dan abrupt. Daarbij is de karakterisering van beslissingen van boeren in rurale regio's gebaseerd op empirische data en dat beperkt het gebruik ervan tot het verleden en de huidige situatie. Tenslotte vereist de karakterisatie en allocatie van verschillende typen van beslissingsstrategieën binnen regio's grote datasets.

In dit proefschrift wordt een actorgerichte benadering beschreven die landgebruiksveranderingen probeert te verklaren en simuleren als een reactie van boeren op socio-economische en biofysische veranderingsprocessen. Deze aanpak werd geïmplementeerd in een 'agent-based' raamwerk dat verschillende concepten en hulpmiddelen combineert: de bereidheid en capaciteit van boeren, besluitvormingscorridors, typologieën van '*agents*' en beslissingsmechanismen gebaseerd op kansberekening. De beschrijving en implementatie van dit modelleerraamwerk heeft verschillende bijdragen gehad aan het onderzoek naar landgebruik. Dankzij het gebruik van dit raamwerk werd het mogelijk om landveranderingsprocessen te simuleren in rurale regio's door de ontwikkeling van een empirisch ABM. Bovendien leverde het een nadrukkelijke koppeling op van de besluiten van boeren en landgebruiksveranderingsprocessen op verschillende niveaus: het veldniveau, boerderijniveau en regionale niveau. Tenslotte kan dit algemene raamwerk ook nog worden toegepast voor andere regio's en andere landveranderingsprocessen. Niettemin heeft ook deze benadering nog zijn beperkingen. De complexiteit en het gebrek aan data zorgen ervoor dat de besluitvorming in rurale regio's moeilijk helemaal te doorgronden is, laat staan te voorspellen door de gelimiteerde statistische validatie van het ABM. Daarnaast is de stochastische aanpak die gehanteerd wordt in het raamwerk misschien wel een robuuste manier om besluitvorming voor te stellen en te simuleren, maar de betekenis van de gehanteerde kansen is vaak onbekend. Tenslotte is het nodig om de invloed en interacties van boeren met andere boeren, beleidsmakers en regionale adviseurs mee te nemen in een poging om boerenbeslissingen beter te begrijpen.

Het agent-based raamwerk is toegepast om landgebruiksveranderingsprocessen in rurale regio's in Nederland te onderzoeken. Met deze toepassing werd het mogelijk om toekomstige socio-economische scenario's met beslissingen van boeren en veranderingen in de landschapsstructuur aan elkaar te koppelen. Het ABM is geparametriseerd aan de hand van een enquête, census data, kadastrale gegevens en landgebruikskaarten. De modelresultaten laten zien hoe de continuering en/of versterking van het huidige landschapsbeleid de verbindingen tussen natuur en landbouw verbetert door de verdere ontwikkeling van natuur en het landschap. Daarentegen, het terugtrekken van dit beleid en het inzetten op liberalisering van de landbouw zal het proces van polarisatie tussen natuur en landschap alleen maar verdiepen wat tot een verlies van culturele en natuurwaarden in de regio zou kunnen leiden. Hoewel de dynamiek van de regionale landschapspatronen niet volledig afhangt van de acties van boeren alleen, kunnen de verschillende besluitvormingsstrategieën de landschapstructuur wel degelijk op verschillende manieren beïnvloeden. Waar sommige strategieën een actieve rol hebben in het veranderen van het landschap, zijn andere wat meer passief. Dit versterkt de toegevoegde waarde van het incorporeren van de diversiteit van besluitvorming in regionaal onderzoek. Deze toepassing benadrukt ook dat participatie van stakeholders de onzekerheid van modelleerprocessen kan reduceren.

Het agent-based raamwerk is daarnaast toegepast in een rurale regio in Australië om landgebruiksveranderingsprocessen als resultaat van de vrijwillige deelname van boeren in een natuurconserveringsprogramma te onderzoeken. Met deze toepassing werd het mogelijk om de participatie van boeren in dit programma voor het behoud en de restoratie van de oorspronkelijke inheemse vegetatie te linken aan veranderingen in de landschapsstructuur. Voor de parametrisatie van het model is gebruik gemaakt van semi-gestructureerde interviews, kadastrale gegevens, en historische landbedekkingskaarten. De resultaten van de interviews identificeren een aantal barrières van boeren om te participeren in dergelijke programma's. De modelresultaten laten zien dat de bereidheid van boeren samen met hun capaciteit om te participeren een sleutelrol kunnen spelen in de restoratie van inheemse vegetatie in de regio, en meer specifiek de restoratie van bedreigde ecosystemen. De resultaten benadrukken hoe de veranderingen in de bereidheid van boeren als een resultaat van hun participatie de inheems vegetatie kunnen doen toenemen, of juist afnemen. Deze toepassing demonstreert dat het gebruik van kwalitatieve data de stochastische benaderingen van besluitvorming kan ondersteunen en tegelijkertijd een beter inzicht geven in de bereidheid en capaciteit van boeren om deel te nemen in dit soort vrijwillige maatregelen.

Om de toepassingen van deze actorgerichte aanpak te contextualiseren is een vergelijking gemaakt met andere regionale ABM's. Daaruit kan worden geconcludeerd dat de actorgerichte benadering die wordt beschreven in dit proefschrift landveranderingsprocessen modelleert als een multi-level proces, waarin non-linerariteit en padafhankelijkheid een rol spelen. Ook laat de toepassing van een actorgerichte benadering zien dat de toevoeging van individuele besluitvorming een toegevoegde waarde heeft voor het begrip van landveranderingsprocessen op een regionale schaal. Meer specifiek laat het zien hoe individuele boeren verschillend kunnen reageren op veranderingen in beleid en hoe deze reacties op hun beurt weer leiden tot ruimtelijke gevolgen in de structuur van het landschap.

Er zijn echter ook nog enkele uitdagingen die met deze aanpak niet worden meegenomen. Deze uitdagingen omvatten bijvoorbeeld het verklaren van andere landveranderingsprocessen zoals verstedelijking, de uitwerking van sociale netwerken, model validatie en de temporele dynamiek van landveranderingsprocessen, stakeholderparticipatie en het gebruik van ABM's in beleidsvormingsprocessen. Ondanks deze beperkingen vormt dit proefschrift een conceptuele en methodologische stap in de verbetering van de analyse en het begrip van regionale landveranderingsprocessen zoals ze voortkomen uit verschillende biofysische en socio-economische actoren en factoren die op elkaar inwerken op verschillende organisatorische, ruimtelijke en temporele schaalniveaus.

About the author

Curriculum Vitae

Diego Valbuena was born on the 14^{th} of June 1978 in Bogotá, Colombia. He attended secondary school in Bogotá. From 1996 to 2002, he followed his undergraduate studies in Ecology at the Pontificia Univerisdad Javeriana in Bogotá. In 2001, he worked as a research assistant at the Universidad del Tolima for 6 months. This was the starting point of his BSc. thesis: "General landscape description of a dryland (Huila – Colombia)", which he finished in 2002. After a year in France, he started a Master in Spatial Planning at Wageningen University. There, he worked as a research assistant during 5 months at Alterra on the project "Synergy between the National Ecological Network and Green-veining: woodland plant species". He finished his MSc. thesis in 2004 on "Land use change models as planning tools: tropical deforestation in Colombia and the CLUE-S model". After his MSc. graduation, he worked for 4 months at the IRD in France on the understanding of forest-agriculture transition in Southeast Asia. This dissertation started in February 2006 and finished in June 2010.

Publications

Valbuena, D., Verburg, P.H., Bregt, A.K. 2008. A method to define a typology for agent-based analysis in regional land-use research. *Agriculture, Ecosystems and Environment*. 128: 27 – 36.

Valbuena, D., Verburg, P.H., Bregt, A.K. Ligtenberg, A. 2010. An agent-based approach to model land-use change at a regional scale. *Landscape Ecology*. 25(2): 185-199

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PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

The C.T. De Wit Graduate School PE&RC
PRODUCTION ECOLOGY & RESOURCE CONSERVATION

Review of Literature (4.2 ECTS)
- The background of the proposal is based on an extensive literature review as agreed with the supervisors

Writing of Project Proposal (2 ECTS)
- Combining actor and pattern-oriented approaches in land-use research methods for the development of a discussion-support tool (2006)

Laboratory Training and Working Visits (4.3 ECTS)
- Farmers' decisions on protecting secondary vegetation; University of Queensland (2009)

Post-Graduate Courses (9 ECTS)
- Multi-agents systems for natural resource management; Mansholt & PE&RC (2007)
- Complexity in and between social and ecosystems; PE&RC (2007)

Competence Strengthening / Skills Courses (5.4 ECTS)
- Scientific writing; CENTA (2006)
- Basic statistics; PE&RC (2007)
- Teaching and supervising thesis students; Docent Ondersteuning (2007)
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Discussion Groups / Local Seminars and Other Scientific Meetings (5 ECTS)
- Spatial methods (SPAM) (2006/2007)
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