Resilience in rural social-ecological systems:

A spatially explicit agent-based modelling approach

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Contents

1. Introduction

1.1 Background

Following sustainability, resilience now seems to be an emerging concept in rural policy (Wilson, 2012). The term is more and more frequently used by both rural policy makers and scientists, and it seems that resilience is set to join 'sustainability' to be another means by which we look at the widening gap between human demands and conserving rural areas[1] (Van Oudenhoven et al., 2011; FAO, 2012). While sustainability is about continuous processes of growth, long-term consumption and production, and seeking continuity of performance, resilience can be seen as a critical factor of sustainability coming up with concepts like the capacity to cope with and adapt to change (Plummer and Armitage, 2007; Turner, 2010). Unlike sustainability, resilience can be desirable or undesirable. For example, systems with corrupt dictatorships that decrease human well-being can be highly resilient, although they are not desirable (Carpenter et al., 2001). Walker and Salt (2006) proposed that any attempt at sustainable development that does not explicitly acknowledge the resilience of a system leads to a malfunctioning system that does not provide the goods and services that are expected. Furthermore, they state that 'the key to sustainability lies in enhancing the resilience of the coupled social and ecological system, not in optimizing isolated components of the system (Walker and Salt 2006, p. 9).

Stemming from ecology (Holling, 1973), the concept later appeared in various other scientific disciplines such as psychology, political science and economics. Given the different disciplinary perspectives from which the notion of resilience has been analysed, all agree that any discussion of resilience needs to acknowledge the subjective nature of the term. Anderies et al. (2006a) therefore concludes that it is not appropriate to describe resilience-based research as a 'theory', but more as a collection of ideas about how to interpret complex systems. The generally accepted definition of resilience is 'the capacity of a system to absorb disturbance, undergo change, and retain the same essential functions, structure, identity and feedbacks' (Holling, 1973; Carpenter et al., 2001). Studies of resilience have shown that systems spend by far the majority of their time in periods of gradual stresses, to suddenly be interrupted by shorter, episodic disturbances that may reconfigure the system (Gunderson and Holling, 2002). Stresses need to be distinguished from disturbances, since different strategies are required to cope with these two types of changes. A stress is an enduring pressure, thus offering a certain level of predictability (e.g. ongoing agricultural intensification that may threaten environmental and eventually production outcomes) (Scoones et al 2007). White and Pickett (1985, p. 7) define a disturbance as 'any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment'.

Stresses such as globalization, climate change and the European Common Agricultural Policy (CAP) reforms increasingly challenge the governance of European rural areas. These stresses sometimes bring forth abrupt disturbances, such as sudden high output price peaks and falls, floods and droughts, and massive outbreaks of animal diseases (BSE, avian influenza) which can cause a severe loss of e.g. welfare, culture and society, and negatively affects a rural areas' environmental and socio-economic development. Given the great value that society attaches to rural landscapes in Europe's densely

[1] Rural areas are defined as 'isolated areas away from more dynamic centers of decision making, with economic and social structures closely dependent on agricultural activity. With environment and natural resources simultaneously conditioned by the activities exerted by the population' (Ambrosio-Albala and Delgado, 2008, p. 3). The terms 'rural area' and 'rural landscape' are used interchangeably throughout this thesis, both referring to this definition.

populated areas (Pedroli et al., 2007), many have denoted the important role that policies can play in steering how rural areas respond to these changes, both in the short and long run (see e.g. Walker et al., 2002; Janssen and Ostrom, 2006; Schlüter and Pahl-Wostl, 2007).

In order to support rural decision-making for coping with these disturbances, there is a growing recognition that an interdisciplinary approach is needed, considering the rural area as a social-ecological system (SES) in which the interdependence between socio-economic (i.e. farming practices) and biophysical components (i.e. ecosystem services) is taken into account across spatial and temporal scales (Berkes, 1998; Cumming, 2011). The behaviour of these complex non-linear SESs is highly unpredictable, and the effects of disturbances can be highly uncertain. Research suggests that rural SESs can be understood as a complex adaptive system, with actors (e.g. farmers, policy makers, consumers) each having their own preferences and perceptions and responding to each other, their environment and external influences. The resulting complex interactions lead to spatial variation in patterns and processes on different scales (Holling, 2001).

Over the past decade, resilience has been promoted as a concept for guiding the management of SESs. However, most studies that explore resilience use it as a metaphor or theoretical construct (Wilson, 2010; Darnhofer, 2010; Van Apeldoorn et al., 2011; Cabell and Oelofse, 2012) because it is difficult to measure due to its abstract and multidimensional nature. Cutter (2008, p. 604) states that 'despite various attempts for describing and assessing resilience, none of the metaphorical and theoretical models have progressed to the operational stages where they effectively measure and monitor resilience at the local level'. However, to be able to use resilience in the management of rural SESs, the concept needs to be made operational and measurable (Cumming et al., 2005). Therefore Carpenter et al. (2001), Cumming et al. (2005) and Cabell and Oelofse (2012) argue that there is a need for further research in this area aiming at the development of measurable criteria that can be considered as proxies (indicators) for the resilience of the system. This thesis contributes to scientific literature by operationalizing the concept of resilience into measurable criteria for the rural SES, and by testing their behaviour using a modelling approach.

1.2 Operationalizing resilience using an agent-based modelling approach

Modelling has been used in resilience research to study the dynamics and management of human and natural systems when faced with unprecedented disturbances. Early resilience models follow an ecological modelling approach in which the human behaviour is simply represented through changes in the rates of an environmental variable (e.g. changes in phosphorous concentrations, grazing management in rangelands) (see e.g. Perrings and Walker, 1997; Carpenter et al., 1999; Anderies et al., 2002 and see Schlüter et al., 2012 for literature overview). In recent years, resilience models have included more and more sophisticated human behaviour explicitly addressing the two-way interactions between human actors represented by their resource allocation decision-making and the environmental system of which they are a part. Modelling human decisions in SESs by means of an agent-based modelling (ABM) approach has become a popular tool that has been employed over the past decades to understand system complexity and non-linear behaviour (see e.g. Happe et al., 2009; Brady et al., 2012; Schlüter et al., 2012; An, 2012). However, when it comes to using ABM for the operationalization of resilience, only a few studies empirically operationalize the concept in their simulations, using system-specific definitions that are not all measurable (see Schlüter and Pahl-Wostl, 2007; Schlüter et al., 2009; Janssen and Carpenter, 1999; Leslie et al., 2009). In this thesis, I propose an ABM approach that explicitly addresses the two-way interactions between rural actors, in this case farmers, represented by their resource allocation decision-making and the environmental system, represented by the rural landscape. When compared to other existing ABMs, the Spatially Explicit Rural Agent-based model (SERA), developed in this thesis, extends their work by putting more emphasis on the interdisciplinary character of the rural SES, by including a realistic natural environment (e.g. by including detailed maps on current land use, soil quality and crop suitability) and capturing more social interactions between rural farm agents. Furthermore, extensive sensitivity analysis was performed to gain insight into how the model responds to changes in parameter values. In this way more insight is gained into the complex behaviour of the rural SES in response to disturbances, which is useful when testing the behaviour of the measurable resilience criteria. Rural policy makers and managers can use SERA and the measurable resilience criteria to evaluate the contribution of rural policy scenarios to enhancing resilience in rural SESs.

1.3 Research objective

The general objective of this research is to explore how the concept of resilience can be operationalized and implemented into decision-making on the management of rural social-ecological systems. This general objective can be divided into two sub goals: The first objective aims to identify criteria that can be considered as indicators for a rural SESs resilience. The second objective aims at assessing the behaviour of these indicators in an experimental setting, capturing the complex dynamics of rural SESs by means of SERA. By this I attempt to provide management advice that takes the coevolving nature of rural SESs into account and supports strategies to cope with uncertainty.

These objectives are formulated into the following research questions:

1. What constitutes resilience in rural social-ecological systems, and how can rural development policies be evaluated, based on criteria for building resilience? *(Chapter 2)*
2. How can the interdependence between socio-economic and biophysical components in rural SESs be explored across spatial and temporal scales by means of a spatially explicit agent-based model, and how does this inform governance processes for rural development? *(Chapter 3)*
3. How sensitive is the spatially explicit rural agent-based model to variations of parameters and inputs and how does this influence model outputs? *(Chapter 4)*
4. How can governmental incentives to foster rural landscape cohesion for biodiversity be made effective under fluctuating market conditions, and thereby increase the landscapes ecological resilience? *(Chapter 5)*
5. What are the potentials and limitations of operationalizing resilience in rural social-ecological systems through measurable indicators, and how can this insight contribute to rural management and policy making? *(Chapter 6)*

1.4 Study area

To answer the research questions, the concepts described in this thesis are applied to the rural area Winterswijk, which is located in the eastern part of the Netherlands. From a landscape perspective, the area represents a highly valued cultural-historic landscape where small-scale agriculture and nature areas are closely related. This spatial structure has resulted in a synergic development between nature conservation, social and economic development and recreational and cultural fruition (Provincie Gelderland, 2005). Figure 1.1 gives an overview of the area.

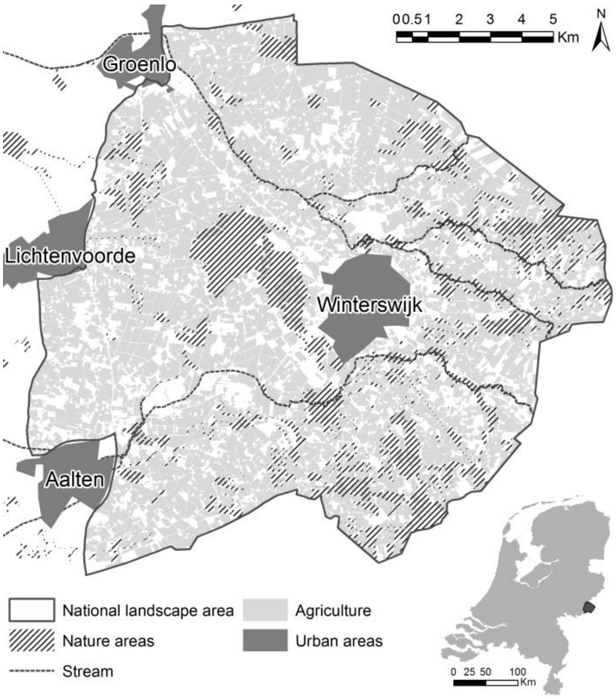

Figure 1.1: The study area Winterswijk

Landscape attributes are characterized by small fields surrounded by hedges or wooded banks (Korevaar et al., 2006; Mastboom, 1996). The size of the area is approximately 22,000 ha, in which 634 farms are present (Agricultural Census, reference year 2010). Dairy production is the most important agricultural sector in the region as it covers 60% of the main production area. For the initialization of SERA I therefore selected 201 specialized dairy farms. Two reference years were used for input data: 2008 for Chapters 3 and 4 and 5, and reference year 2010 for Chapter 6 (both Agricultural Census data and GIS-data).

1.5 Outline of the thesis

Figure 1.2 gives an overview of the outline of this thesis. It consists of 7 chapters, including this introduction. Chapters 2 and 3 form the conceptual core of the thesis. Chapter 2 focuses on what resilience means in the rural context and presents criteria for a policy objectives evaluation framework to analyse how rural development policies contribute to the resilience of rural areas. This framework will be used later on in Chapter 6 to operationalize resilience at a regional level. In Chapter 3 SERA is developed to provide insight into the dynamics of the ecological and socio-economic characteristics of the rural SES, and to evaluate how the contribution of rural policies to resilience could be made effective while imposing disturbances to the system.

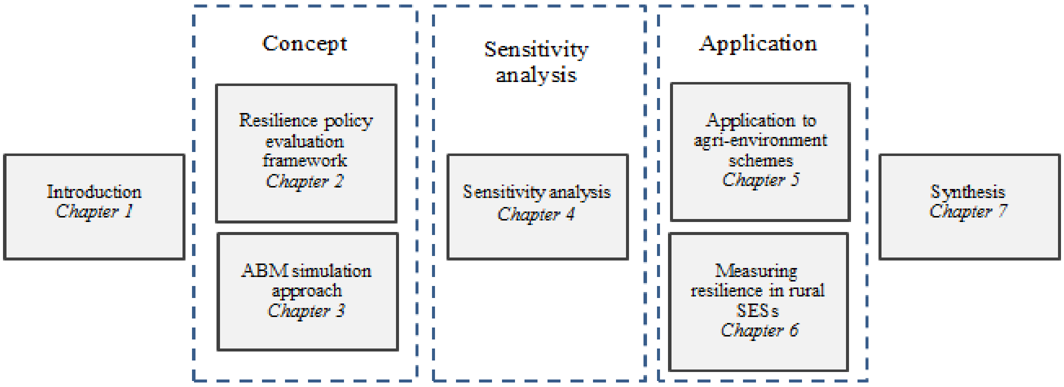

Figure 1.2: Schematic outline of this thesis

Chapter 4 performs a sensitivity analysis to study the effects of variations of parameters on outputs generated by SERA. The functionality of SERA is illustrated in Chapter 5 by assessing how a government incentive fostering landscape cohesion for biodiversity through agri-environment schemes influences farmers' decisions while being affected by fluctuating market conditions. Chapter 6 operationalizes the policy objectives evaluation framework introduced in Chapter 2 into measurable indicators to assess the resilience of the rural social-ecological system on a regional level. SERA, which has been proposed earlier in Chapter 3, is used to gain insight into the way the resilience criteria behave in times of disturbances, while experimenting with different policy regimes. Chapter 7 presents the main findings of this thesis, as well as the discussion of the research questions and the contribution of this thesis to resilience research and policy-making processes.

2. A resilience-based policy evaluation framework: Application to European rural development policies

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Abstract

Given the major changes that rural areas have undergone, and are continuing to undergo, serious problems of achieving sustainable development are being experienced. These changes have multiple characters, varying from changes in ecosystem conditions to changes in socio-economic impacts, due to, for example, food- and financial crises. Nowadays, there is an increasing awareness of the need to develop rural policies that support adaptive strategies of stakeholders in response to a disturbance. We propose that resilience thinking offers a framework that could be helpful in the governance of rural changes. This framework is based on the complexity of the social–ecological system and takes into account the unpredictable future, as it emphasizes adaptive approaches to management. As such, it helps evaluate to what extent rural development policies contribute to the resilience of rural areas. Nine criteria were developed including thirteen specifications. In order to evaluate the usability and usefulness of the proposed framework, a case study has been performed that specifically investigated the degree of resilience of a European rural development policy (i.e. the spending of extra funds generated through compulsory modulation under the 2009 Health Check in the Netherlands).

2.1 Introduction

Rural areas in the European Union cover 90% of the territory and hold 56% of its population (EU-27) (EC, 2009a). Agriculture and forestry, the main land use types, play a key role in the management of natural resources and in determining the rural landscape. These areas have undergone, and are still undergoing, major changes. Intensification, marginalization, specialization and concentration have resulted in an increasing spatial differentiation of rural areas in terms of economic, social and environmental outcomes. For example, while in some regions farmers maximize economic value by effectively producing food for the world market, in others multifunctional activities are developed to obtain income from a range of activities. In still other regions, predominantly young people leave their families to seek a livelihood elsewhere, which ultimately results in depopulation and ageing.

Accepting sustainable development as a main framework for decision making in the EU (Lisbon strategy), it can be questioned how land use in rural areas can be adapted to upcoming demands according to the three Pillars of sustainable development – economic, social and environmental (EC, 2004). This question is particularly relevant in situations where the income of farmers is highly unpredictable due to, for example, fluctuations of world market prices, increasingly frequent droughts and floods under a changing climate regime, and massive outbreaks of animal diseases (BSE, avian influenza). Such events may also cause a loss of public support for agriculture. There is thus a need for a framework to assess the long-term implications of rural policy from the perspective of sustainable development.

For systems with unpredictable behaviour, the concept of resilience has been proposed as a cornerstone of sustainability (Walker and Salt, 2006; Plummer and Armitage, 2007; Turner, 2010). Resilience is defined as 'the capacity of a system to absorb disturbance, undergo change, and retain the same essential functions, structure, identity and feedbacks' (Holling, 1973; Carpenter et al., 2001; Holling, 2001; Walker et al., 2002; Walker et al., 2004). White and Pickett (1985, p. 7) define a disturbance as 'any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment'. Walker and Salt (2006) proposed that any attempt for sustainable development that does not explicitly acknowledge the resilience of a system leads to a malfunctioning system which does not provide the goods and services that are expected. They state that 'the key to sustainability lies in enhancing the resilience of the social-ecological systems, not in optimizing isolated components of the system' (Walker and Salt, 2006, p. 9). A resilient rural system is believed to possess a greater capacity for preventing unwelcome surprises in the face of external disturbances, and therefore a greater capacity to continue to provide the goods and services that support our quality of life (Walker and Salt, 2006). What constitutes and enhances resilience has been studied extensively over the past decade, while the resilience of social, economic and natural resource management aspects within rural areas have received considerable attention (Walker et al., 2004; Stayner, 2005; Plummer and Armitage, 2007; ; Nkhata et al., 2008; Van der Ploeg and Marsden, 2008; Wilson, 2010). However, the impact of agricultural policies on the development of resilience in rural areas has not yet been considered in literature.

This chapter aims to fill this scientific gap by developing criteria for a policy objectives evaluation framework that analyzes how rural development policies contribute to the resilience of rural areas. The framework is applied to European rural development policies, specifically focusing on the spending of compulsory modulation budget. Based on this research aim, our research question is: How can we evaluate rural development policies, based on criteria for building resilience in rural areas? We limit our aim to the evaluation of policy *objectives*, considering the ex-ante evaluation of rural development policies. For reasons of practicality (see Section 2.5), the final outcome of the policy programmes falls outside our scope. Note that the framework that we provide does not represent a fixed-and-ready instrument to apply in all rural policies. We present it as a first attempt to facilitate the implementation of the results of scientific research on resilience into all stages of rural policy developments.

The structure of this chapter is as follows. In Section 2.2, resilience thinking is introduced as a key to sustainable development. Section 2.3 defines criteria for building resilience in rural systems, which are then used to develop a policy objectives evaluation framework. In Section 2.4 the developed policy objectives evaluation framework is applied to a case study– the spending of 2009 Health Check compulsory modulation in the Netherlands. Finally, the applicability and suitability of the framework is evaluated in Section 2.5 and suggestions and recommendations for further development are given.

2.2 Rural social-ecological systems and resilience

2.2.1 Defining rural social-ecological systems

In this thesis, we define rural areas as 'isolated areas away from more dynamic centers of activity, that are set aside from centers of decision making, with economic and social structures closely dependent on agricultural activity. With environment and natural resources simultaneously conditioned by the activities exerted by the population' (Ambrosio-Albala and Delgado, 2008, p.3). According to this multi-sectoral definition, rural areas can be denoted as social-ecological systems (SES), comprised of social and economic (or human) and ecological (or biophysical) characteristics. This concept recognizes that social, economic and biophysical characteristics considered in isolation can each provide a partial understanding at best, and that all three aspects must be taken together to obtain a full understanding of the system dynamics (Berkes, 2003). Within rural SESs, financial economics plays a large role, as farmers need to ensure both the short-term and long-term survival of their farm. These farmers and other rural stakeholders together form the social part of the system – the rural community. Together they have a large influence on ecological structures and processes within the system, and in turn they depend on these natural resources as their main source of income (Darnhofer, 2010). Figure 2.1 shows a graphical representation of the main characteristics and interrelationships within the rural SES. Furthermore, nine criteria for resilience development are shown, which will be discussed in Section 2.3.

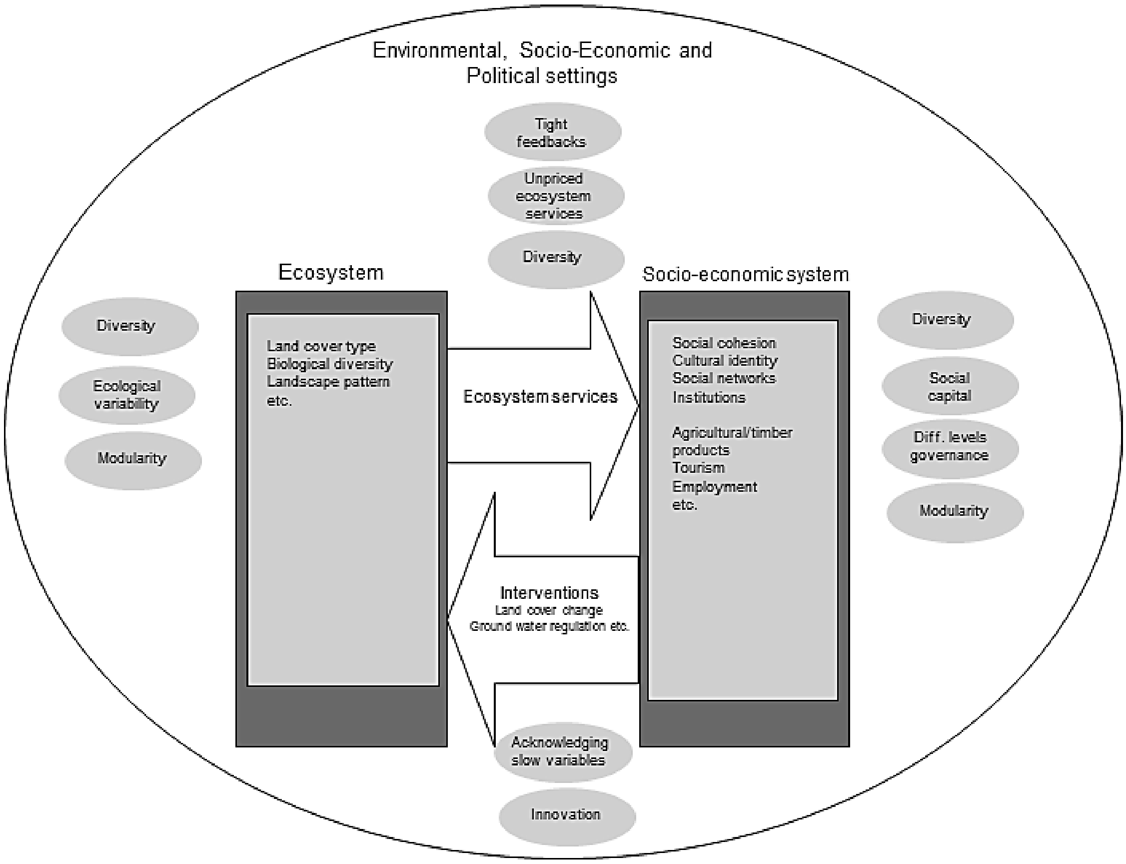

Figure 2.1: Characteristics and interrelationships within the rural social-ecological system. The boxes represent the main characteristics, the arrows the interactions between them. The circles represent nine criteria for resilience development, which are discussed in Section 2.3.

Figure 2.1 shows that the human subsystems, subsumed in the term ‘Socio-economic system’, are comprised of individuals, groups, networks and institutions (rules, regulations and procedures). These actors intervene with the ecological system (termed ‘Ecosystem’) which basically can be defined as ‘a biotic community or assemblage and its associated physical environment in a specific place’ (Pickett and Cadenasso, 2002, p.2). Biological diversity, land cover type and spatial landscape pattern are examples of ecosystem characteristics. The socio-economic system is comprised of a social component and an economic one. Processes within each of these components play an important role in determining interventions in the ecosystem, which directly and indirectly modify the ecosystem structure and function (Rescia et al., 2008). Examples of human interventions are the conversion of natural ecosystems into agricultural systems, for instance, planting of forests, irrigation of land, and the construction of flood control reservoirs. In turn, the ecosystem provides ecosystem services to the socio-economic system. Also negative feedback can occur (diseconomies) as a reaction to the human interventions. Figure 2.1 shows that the governmental system, here denoted as ‘Environmental, Socio-Economic and Political settings’ is treated as an external influence, imposed upon the system as a precondition and unaffected by it.

2.2.2 Disturbances

We focus on the resilience of the system in the light of (future) disturbances. This is a dynamic challenge in which it may be preferable, at certain times, to enhance resilience, e.g. when a system is in a state that is desirable, and at other times to erode and help transform the system, e.g. when the system is in an undesirable state (Lebel, 2006). Uncertainties and nonlinearities arising from sudden disturbances often result in complex interactions between structures and processes operating at different scales in the rural SES. With emphasizing these scale dependencies, we are referring to the term ‘panarchy’ introduced by Gunderson and Holling (2002) to describe the cross-scale and dynamic character of interactions between humans and natural systems. For example, the most recent European outbreak of foot and mouth disease in the UK not only had an economic effect on farmers, but affected the whole food chain, i.e. cattle feed companies and slaughterhouses, and the public opinion on the conventional-industrial way of food production. In this way both the social and the economic characteristics of the SES were affected, but these effects were also visible on a national and international scale. With respect to the impact of disturbances on the separate subsystems of the rural SESs, we emphasize, in line with Van Oudenhoven et al. (2011), that the resilience of rural SESs depends as much on results of social-ecological interactions, in which rural stakeholders adapt to their environment and change that environment in the process, as it does on ecological characteristics (biodiversity, habitat, ecosystem services) and social characteristics (institutions, networks, education) of the system.

Given that disturbances are essential parts in theories on resilience in SESs (see e.g. Carpenter et al., 2001; Berkes, 2003) few studies articulate what is meant by disturbance (Schoon and Cox, 2012). Most studies describe a disturbance using the general definition of White and Pickett (1985), as stated in Section 2.1. This definition leaves out typologies of disturbances, taking into account the factors intensity, frequency and duration, as adopted from Dingman’s book *Physical Hydrology* (Dingman, 1994). For the case of rural SESs discussed in this chapter we exclude disturbances that destroy the biophysical system. Hence, we assume that farming activities and agricultural production can be continued and that the area remains habitable to rural communities. This rules out disturbances of a higher order, having a high intensity, a high frequency or a lengthy duration, like nuclear disasters, tsunamis, earthquakes or combinations of these. In the literature, classifications exist for these types of natural disasters, taking the Fujita scale for tornadoes and the Richter magnitude scale for earthquakes as an example. Tornadoes upward of F4 and earthquakes with a magnitude of eight and higher cause such a level of damage that the area becomes inhabitable and rural economic activity is not possible for a long period of time. Moreover, for socio-economic disturbances (e.g. as a result of economic crises, political decisions) we propose to keep all possibilities open.

2.3 Developing a Policy Objectives Evaluation Framework

2.3.1 Setting criteria for resilience management in European rural SESs

Folke (2002) encourages the integration of resilience criteria into policy development. Although he does not present a list of criteria for developing policies towards resilient SESs, he recommends that whenever policies are developed, interrelations between ecosystems and human society should be highlighted. He also states that policies should allow for the flexible collaboration and management of SESs with open institutions that allow for learning and innovation on multiple levels. Finally, he mentions that these policies should focus on sustaining key ecological variables and enhancing diversity to cope with uncertainty. Given that no criteria concerning the development of resilience in rural SESs are presently available to apply in rural policy making, this chapter presents a first attempt to provide a framework for evaluating the implications of rural development policies for the resilience of rural areas. The framework addresses ex-ante policy documents, in which the general intent of government institutions with respect to the issue in question is described. Hence, this considers ex-ante evaluation. The same type of approach is seen in Iglesias and Buono (2009) evaluating water policies in Mediterranean countries and Hughey and Hickling (2006) evaluating ungulate management policies in New Zealand. Both studies make use of criteria with underlying evaluation questions or specifications to evaluate the respective policies. Ex-post evaluation falls outside the scope of this chapter, as this demands empirical data on the nature of disturbances, how and to what extent the policy has been implemented, effectiveness of the policy, etc. Each rural SES has its own unique characteristics, disturbances and politics of place. To policy makers, the criteria can help to elucidate whether and how rural development policies can contribute to the ability of rural SESs to respond to sudden disturbances.

In literature, we found only one study that attempts to provide a comprehensive list of criteria for resilience development that cover the three dimensions of the SES in an equivalent way. In their book *Resilience Thinking*, Walker and Salt (2006) discuss nine resilience attributes towards a resilient world: diversity, variability, modularity, acknowledging slow variables, tight feedbacks, social capital, innovation, overlap in governance, and ecosystem services. Their main focus is not to provide an exhaustive list of criteria, but to compose a list that covers the broader themes that revolve around humans existing within SESs. A comparable list was compiled by Levin (1999), but this author primarily focuses on the ecological system and their management in the case of disasters. Also Van Oudenhoven et al. (2011) provides a list of so-called 'social-ecological indicators for landscape resilience', but these indicators primarily consider nature conservation in agrarian landscapes.

In this chapter we make use of the list by Walker and Salt (2006) because of its explicit link with SES, because it shows significant overlap with the policy recommendations by Folke (2002), and because it is the only list available that covers a large number of aspects of the SES. Taking the list as a starting point, we translate the proposed criteria to the case of rural SESs, by describing each criterion within its rural social-ecological context and proposing specifications that make each of these criteria applicable in judging and evaluating policy measures for resilience development in rural SESs. The specifications are generic and abstract, which makes them easily transferable to other case studies. However, when implemented into specific case studies, they will need to be adjusted. Furthermore, we assume that equal weights are given to the criteria, which could serve as an interesting topic for future discussion. Here, we follow Van Oudenhoven et al. (2011), who denote that criteria that cover the ecological, economic and social aspects of the rural SES should be dealt with in an equivalent way, as this can be an important subject of discussion for rural policy makers.

Figure 2.1 shows how the nine criteria for resilience development are embedded in the rural SES. In line with Walker and Salt (2006), two specifications are applicable to both the ecological and socio-economic characteristic (diversity and modularity). The diversity criterion can also be detected as an interaction from the ecosystem to the socio-economic system through providing ecosystem services. The remaining seven focus on a single system characteristic, either ecological or socio-economic, or focus specifically on an interaction between both. Specifications are provided for each of these circles. The nine criteria and corresponding specifications will now be discussed individually.

Diversity

According to Walker and Salt (2006), diversity plays a crucial role in developing resilience since system components can replace or compensate for each other in times of disturbances. Promoting and sustaining diversity in all forms (biophysical, landscape, social and economic) would therefore enhance resilience. Figure 2.1 shows that diversity applies to ecosystem- and socio-economic system characteristics. When dealing with ecosystem characteristics, the diversity of species, ecosystems and crops augments the reliability of ecosystem services provisioning (see e.g. Isbell et al., 2011). These ecosystem services and disservices, which are the benefits and disbenefits that an ecosystem potentially provides to the socio-economic system, can also be related to diversity (Reid, 2005; Escobedo et al., 2011). Figure 2.1 therefore also places diversity at the ecosystem services interaction-arrow. Different services can be distinguished, namely provisioning services (i.e. food, fibre production), regulating services (i.e. water-, disease- and air quality regulation), cultural services (i.e. recreation and cultural history) and supporting services (i.e. soil formation, nutrient cycling) (Reid, 2005; Wallace, 2007). As rural stakeholders depend on the ecosystem services provided by the ecosystem, they benefit from a constant delivery of diverse ecosystem services, which can be seen as a way to enhance resilience. Their reliability of production will increase, as well as their quality of life. We propose that the SES increases in resilience with an increase of the number of services that are recognized as beneficial by the rural community. Spatial diversity (heterogeneity) also plays a significant role for the resilience of species populations on the landscape level. For example, Oliver et al. (2010) show that spatial heterogeneity in landscapes offers a range of resources to species populations, which in turn leads to more resilient populations in times of climatic extremes.

Diversity under the socio-economic system can be subdivided into diversity of economic opportunities and resource endowments (land, labour, capital) and diversity of social relationships (i.e. formal contracts, neighborly help). For farmers, Darnhofer (2010) proposes on-farm diversification as an indicator for resilience, because if farmers diversify their on-farm activities they are not solely dependent on primary agricultural production, so that their income would fluctuate less, thereby increasing their economic persistence. Examples of these multi-functional agricultural activities are farm campsites, on-farm processing, care activities and energy production. However, policies promoting on-farm diversification could also have undesirable outcomes in the sense that diversified farms may suffer from low economic performance through lack of markets and increased production costs (Garnevska et al., 2006). Therefore, with respect to rural policy development, it is important to give attention to adequateness in targeting incentives for creating diversity and heterogeneity within rural SESs. Whether traditional rural development policies comply with targets towards diversity development depends on their level of detail. Specific policies aiming at stimulating the production of e.g. particular agricultural products, ecosystem services or public goods would lead to a homogenization rather than enforcing the spatial diversity of goods and service production in relation to the spatial variety of physical and cultural regional characteristics. We therefore propose the following specifications for policy evaluation:

- *Diversity of species, ecosystem types and crops (ecosystem characteristics)*
- *Diversification of agricultural goods and services (socio-economic system characteristics)*
- *Diversity of ecosystem services types considered beneficial (interaction ecosystem → socio-economic system)*

Ecological variability

In Figure 2.1, ecological variability applies to the ecosystem characteristics of the rural SES. According to Walker and Salt (2006), allowing for ecological disturbances such as floods, fire and outbreaks of species populations to occur, and encouraging working with it, adapting to it and embracing it, leads to the development of resilience in rural SESs. Holling and Meffe (1996) advocated replacing stability as a management paradigm by resilience. Allowing local fires in forests, for example, increases the fire resistance because it maintains a spatial mosaic of different stages in vegetation succession (Romme et al., 2011). Management by farmers aimed at preventing growth of forests in river beds decreases flood risk, along with producing services like water retention, recreation, biodiversity and food production (Baptist et al., 2004; Billen and Lambert, 2005). The Dutch ‘Room for the River’ policy program has incorporated this ecological variability principle to restore the natural discharge capacity in times of climate change. This example shows that adaptive management takes place at different levels; from the institutional level to the local stakeholder level. Instead of preventing the rural ecosystem from flooding, resilience is developed through adaptive management of the flood plains. In the terms of Walker and Salt (2006), disturbances are embraced and local stakeholders adapt to it.

To evaluate the contribution of ecological variability to resilience development within rural development policies, we formulate the following specification.

- *Adaptive management of rural ecosystem (ecosystem characteristics)*

Modularity

Modularity means that a system comprises individual functional parts or modules that can evolve independently (Berkes, 2007). In resilient SESs, the modules are loosely linked, but not completely dependent. In this way, disturbances are not rapidly transmitted through the entire system. In Figure 2.1 modularity is related to both the socio-economic system and the ecological system. For ecosystems, Levin and Lubchenco (2008) state that to protect a system’s resilience, adaptive capacities of these ecosystems must be maintained by preserving modularity, heterogeneity, tight feedback loops and redundancy. They defined modularity as the compartmentalization of the system in space, in time, or in organizational structure. Taking epidemiology as an example, it is well understood that diseases do not put all individuals at risk uniformly; rather, risk groups exist, with high mixing rates within these groups and low mixing rates within other groups. Efforts to control a disease should therefore focus on modularity between these groups, thereby minimizing the risk of transmission. A central aspect of theories of modularity is the importance of space, and of the compartmentalization of biodiversity into relatively isolated patches. Earn et al. (2000) theorize that where populations are too tightly connected, disturbances to one will affect all; modularity in the distribution of species allows species to fluctuate independently, forming a buffer for times of unfavourable environmental conditions. Conversely, when local populations are too loosely connected, feedback loops which could have stabilizing functions cannot operate effectively.

With respect to the socio-economic system, literature on industrial management states that modular organizational forms with loosely coupled networks of organizational actors allow the organizational components to be flexibly recombined into a variety of configurations (Schilling and Steensma, 2001). Modular firms rapidly alter their scale and scope through alternative work arrangements and firms can use alliances to access critical capabilities they lack in-house, giving them greater scope of flexibility. The main force driving the use of modularity is the heterogeneity of inputs and demands: ‘The more different inputs there are available to combine within a system, the more numerous the configurations enabled by modularity’ (Schilling and Steensma, 2001, p. 1153). This statement also holds for farmers and other rural stakeholders. Conventional European dairy farmers, for example, usually incorporate imported soybean as a high-protein complement in the feed ration of dairy cows. The soybeans used for animal feeding in Europe are predominantly produced overseas. Substituting imported soybeans with locally-produced alternatives, e.g. rapeseed, beans or peas, decreases the dependency on one type of input, and increases flexibility in times of fluctuating market prices or supply (Lehuger et al., 2009). Modularity can also be applied to outputs–offering a variety of outputs, given heterogeneous demands, can enhance the ability to meet demands with diverse system configurations (Schilling and Steensma, 2001).

Walker and Salt (2006) denote that policies have the tendency to make organizational structures more efficient by decreasing the number of modules in the system. From a resilience perspective, it would be more effective to let go of this regulating purpose by allowing for more ‘fuzzy’ organizational structures. Also with respect to rural development policies, support of single organizational structures or farm structures through subsidy programs, for example, is leading to a decrease in modularity because homogenization of these structures is promoted. To evaluate the extent to which policy makers focus on resilience development through integrating modularity characteristics into their rural development policies, we propose the following specifications:

- *Multiple types of organizational structures and farm structures (socio-economic system characteristics)*
- *Compartmentalization of biodiversity in space, time or organizational structure to enhance the provision of ecosystem services (ecosystem characteristics)*

Acknowledging slow variables

A resilient SES would have policies that focus on ‘slow’ controlling variables (Walker and Salt, 2006). Slow variables are the underlying key variables of a system that do not directly respond to disturbances, whose thresholds determine the capacity to manage the resilience of a system. Examples of slow variables are some of the ecosystem services previously discussed under ‘Diversity’. Regulating and especially supporting ecosystem services are typically slow variables that develop slowly after interventions in the landscape, because they depend on well-established species communities (Isbell et al., 2011). Also for rural SESs, rural stakeholders depend on these variables for their income, recreation activities and quality of life. Figure 2.1 shows that this criterion is related to the interventions from the socio-economic system to the ecosystem. Rural policies under the socio-economic system, triggering the development of resilience in rural SESs, should consider these ‘slow’ variables. We assume that whenever policies are part of a broader policy framework, which is adjusted in the medium- to long term, it takes into account these ‘slow’ variables. Developing policies with a medium- to long-term vision that maintain or develop these slow variables would increase the capacity to manage the resilience of the system. An example of these policies are agri-environment schemes with medium- to long-term contracts, which is an instrument of the government to attempt to influence farmer’s decisions to enhance levels of biodiversity on farmland (Whittingham, 2011). We propose the following specification for policy evaluation:

- *Long-term policy perspective (interaction socio-economic system → ecosystem)*

Tight feedbacks

The difference between modularity, as discussed earlier, and tight feedbacks is that modularity focuses on the type of connectivity and compartmentalization of ecosystems and societies, while the tight feedbacks criterion focuses on the feedback loops within these modules (Levin and Lubchenco, 2008). Walker and Salt (2006) state that SESs that possess tight feedback loops are more resilient. Tight feedback loops are essential for a system’s resilience as they can help to develop the structures that sustain the systems, but they can also create vicious cycles which deteriorate a systems resilience (Levin and Lubchenco, 2008). This suggests that managing resilience should aim for optimum tightness, rather than a maximum tightness. Feedbacks can develop a system’s resilience, but it can also break it down, as they can create cooperation but also facilitate selfishness and greediness. In their book, Walker and Salt (2006) take globalization as an example leading to delayed feedbacks that were once tighter. People of the developed world presently receive only weak signals about the consequences of their consumption patterns, while using natural resources of the developed world. This example shows that feedback loops have a spatial character, focusing on the distance between users and providers of natural resources

In Figure 2.1, tight feedbacks are related to the interactions between the ecosystem and the socio-economic system characteristics of the rural SES, where it represents the provision of natural resources from the ecosystem to the socio-economic system. Within rural SESs, tight feedback loops refer to a small distance between natural resource inputs provided by ecosystem services, and producers and consumers, leading to a rapid localization of direct and indirect effects of production and consumption, which in turn leads to a more effective development of resilience in the rural SES. An example of tight rural feedbacks is a regional farmers market where local producers sell their products to local consumers. Excessive use of local resources is immediately noticed by rural stakeholders, as it affects their spatial environment in a direct way. Van der Ploeg and Roep (2003) call this ‘shortening of the agricultural supply chain’, which is a synonym of ‘deepening’ of the farm activities so that greater added value is created on a local or regional scale. Another example is the use of natural pest control instead of control by chemicals. This can be illustrated with the following example: insects living in semi-natural non-crop landscape elements exert natural pest control in adjacent arable crops, thereby replacing long indirect feedbacks via industries producing pesticides that are spread preventively (Steingröver et al., 2010). For this criterion, we propose two specifications. The first one represents the interactions between local producers and local consumers. The second one focuses on ecosystem services provision:

- *Local supply and demand within the local food supply chain (interaction ecosystem → socio-economic system)*
- *Local solutions to enhance the provision of ecosystem services (interaction ecosystem → socio-economic system)*

Social capital

Social capital is 'the glue that holds society together, in the form of trust, reciprocity and exchanges, social networks and groups' (Bowles and Gintis, 2002, p. 428). Rural communities that are strongly connected are assumed to have an increased capacity to respond to disturbances (Murphy, 2007). In communities that are tightly knit, transaction and monitoring costs are lower. Knowledge and expertise can be exchanged more easily than in low-trust communities, and people might become less risk-averse because of the informal social safety net, created by social capital in the community (Nkhata et al., 2008). However, at the same time, social capital can obstruct development, as dense social networks might be averse towards change, and strong homogeneous communities may discourage exchanges with 'the outside world'. The social capital criterion is related to the socio-economic system characteristics in Figure 2.1. The difference between modularity, tight feedbacks and social capital can be explained by the fact that modularity focuses on the structure of a system, compartmented in different modules. Tight feedbacks focus on the feedback loops between ecosystem and socio-economic system characteristics within individual modules, while social capital tries to give insight into the characteristics of the interactions and networks in the socio-economic system, between rural stakeholders within one individual module. We realize that the concept of social capital contains a broad spectrum of definitions, theories and concepts. For the policy evaluation framework discussed in this chapter, we focus on the purposes of the policy instrument with respect to the stimulation of strong networks between rural stakeholders. The main argument is the great emphasis in the European Union on encouraging the development of rural social networks. The LEADER programme is a good example of a large-scale government initiative that encourages the development of rural social networks, where decision-making power and public funds are shifted from a top-down approach to a bottom-up one in which local stakeholders are continuously involved in rural decision making (Ramos and Delgado, 2003). Therefore we propose the following specification:

- *Strong networks between rural stakeholders (socio-economic system characteristics)*

Innovation

Resilient SESs place an emphasis on learning, experimentation, and embracing change (Smith and Stirling, 2010). A resilient system is characterized by experimentation and embracing disturbances by creating innovations through trying things in a different way. In this way, new opportunities arise, and new resources are made available for system development. Also in European rural SESs, rural stakeholders depend on innovations and experimentation whenever disturbances occur. Policy instruments can have an important role; e.g. whenever policies do not leave room for own initiative and experimental settings, resilience in rural SESs can even be broken down instead of being built up. Therefore, it is important that policies are sensitive to existing and new rural stakeholders' initiatives. This can be illustrated with an example from the Dutch Friesian Woodlands; a small-scale agricultural area in the Northern part of the Netherlands (Renting and Ploeg, 2001). There, policies are developed to promote the training of rural actors in social networks aiming at the management and enhancement of environmental quality. In Figure 2.1 it is shown that the innovation criterion applies to the interventions from the socio-economic system to the ecosystem. As shown in the example of the Friesian Woodlands, learning and new initiatives by rural stakeholders can contribute to the quality of the rural ecosystem. To emphasize the importance of fostering and encouraging rural stakeholder initiatives, we propose the following specification for evaluation:

- *Experiments and new initiatives at local stakeholder level (interaction socio-economic system → ecosystem)*

Different levels of governance

According to Walker and Salt (2006), resilient SESs have institutions that include ‘redundancy’ in their governance structures and a mix of common and private property with overlapping access rights. Redundancy in institutions increases the response diversity and flexibility of a system (Ostrom, 1999). Since many cases of ‘tragedy of the commons’ (i.e. overgrazing, overfishing) are the result of failing governance structures, we apply different levels of governance for rural policy development as an indicator for resilience of the socio-economic system characteristics of the rural SES. To build resilience in rural SESs, it is important that the ratio between the governance structures and the level of detailed policy that they have to execute is in balance (subsidiarity). For example, execution of detailed policies at national level suppresses the role and influence of lower layer governmental institutions. Ostrom (1999) elaborates on active cooperation between farmers and government authorities at multiple levels that lead to an increase in a system’s response diversity, thereby enhancing its resilience in times of disturbances. Therefore we propose the following specification:

- *Diversity in governmental structures and levels of execution (socio-economic system characteristics)*

Unpriced ecosystem services

The term ecosystem services has already been mentioned in relation to the criterion of diversity, focusing on diversity in ecosystem services, and the criterion of acknowledging slow variables, focusing on the slow response and recovery from a disturbance at long temporal scales. As such, the criterion of nonmarket, hence unpriced, ecosystem services seems at first sight to be a specific ecological elaboration of the criterion of acknowledging slow variables. However, whereas slow variables more or less relate to system processes that do not directly respond to disturbances, ecosystem services are the direct and indirect contributions of ecosystems to human welfare. Figure 2.1 shows that this criterion applies to the benefits supplied by the ecosystem to the human welfare in the socio-economic system. In this subsection, we focus on the fact that often ecosystem services are unpaid to society, in the sense that they are provided free of charge. Many of the services that ecosystems provide are unrecognized and considered to be ‘free’ (i.e. nutrient cycling, water purification). However, ecosystem services are vulnerable when disturbances occur, and actors are affected by the malfunctioning of ecosystem services through feedback mechanisms between the biophysical and socio-economic characteristics of the SES. Therefore, conservation of these services is important for the sustainable development of SESs. In purely market-driven economies, these services are ignored. Also in rural SESs, stakeholders depend on ecosystem services for agricultural production, a liveable environment, income from recreation, etc. This makes it important to include these unpriced ecosystem services in the development of policies (Corbera et al., 2007; Swinton et al., 2007), for example by internalizing external costs of losing valuable ecosystem services. In this way, awareness is increased among citizens and active management of ecosystem services can be realized. We propose the following specification for this criterion:

- *Costs for maintaining unpriced ecosystem services (ecosystem characteristics)*

Now that we have discussed the nine criteria for resilience development in rural SESs individually, the criteria can be classified into four groups that correspond to the system characteristics and arrows represented in Figure 2.1. Table 2.1 gives an overview of the four groups that can be distinguished, and repeats again the specifications for each criterion discussed in this section.

Table 2.1: Proposed criteria and specifications for rural development policy evaluation

System characteristics and interrelationships	Specifications
Ecosystem criteria	
Diversity	- Diversity of species, ecosystem types and crops
Ecological Variability	- Adaptive management of rural ecosystems
Modularity	- Compartmentalization of biodiversity in space, time or organizational structure to enhance the provision of ecosystem services
Socio-economic system criteria	
Diversity	- Diversification of agricultural goods and services
Social Capital	- Strong networks between rural stakeholders
Different Levels of Governance	- Diversity in governmental structures and levels of execution
Modularity	- Multiple types of organizational structures and farm structures
Ecosystem services	
Diversity	- Diversity of ecosystem services types considered beneficial
Tight Feedbacks	- Local supply and demand within the local food supply chain - Local solutions to enhance the provision of ecosystem services
Unpriced Ecosystem Services	- Costs for maintaining unpriced ecosystem services
Interventions	
Acknowledging Slow Variables	- Long-term policy perspective
Innovation	- Experiments and new initiatives at local stakeholder level

2.3.2 Application of the framework in policy evaluation

Now that all criteria and specifications have been discussed, the evaluation process will be explained. As discussed in Section 2.3.1, the aim of the proposed framework is to evaluate to what extent rural development policies contribute to the resilience of European rural areas. To that end, the framework focuses on ex-ante evaluation of rural development policies; that is, the *intended* objectives of the policy programmes are evaluated by using the proposed specifications that are summarised in Table 2.1. To evaluate to what extent a specific resilience criterion has been met, we propose three possible scores:

0. *Neglect:* The policy contains no commitment to identify and address the specification.
1. *Awareness:* The policy gives general notions for the importance of the specification, but does not propose any concrete actions or instruments.

2. *Explicit aim:* The policy explicitly refers to the promotion of the specification. A detailed package of policy instruments for the implementation or enhancement of the specification is provided.

The same types of scores are defined by Hughey and Hickling (2006) using five possible scores, and Termorshuizen et al. (2007) using two possible scores. The possible scores we propose are in line with the latter – Termorshuizen et al. (2007) – who subdivide their scoring method in (i) policies in which only awareness of conditions is present (similar to what we label as score '1'), and (ii) policies that actually provide conditions to achieve the actual targets (which we label as score '2'). Based on these scores, an action plan can be formulated to adjust the policy instrument in such a way that it enhances the development of resilience in the rural SES. For this chapter we use equal weightings for each of the nine criteria and corresponding specifications. Discussion on this subject is beyond the scope of this chapter, but may be an interesting topic for future research.

2.4 Evidence from a European case study: Evaluating the impact of modulation in the Netherlands from a resilience perspective

In this section, the proposed policy objectives evaluation framework is applied to a European case study, namely: spending modulation receipts within the Rural Development Programmes of the Netherlands. In Section 2.4.1, a short introduction will be given of the modulation concept within the broader European rural policy framework, while in Section 2.4.2, the policy will be evaluated using the framework proposed in Section 2.3.

2.4.1 Modulation: Shifting from production support toward rural development programs

To keep in line with the requirements under the World Trade Organization (WTO), changes have been made in recent years to the way the EU Common Agricultural Policy (CAP) operates to ensure greater market orientation. The central factors here were the 2003 reforms, which introduced the decoupling of direct payments from production as well as, among other changes, modulation on a compulsory basis for the EU-15 under Article 10 of Council Regulation (EC) No 1782/2003 (EC, 2003). Greater market orientation within the agricultural sector means that the influence the CAP once had on patterns of production through production-related payments and market interventions has significantly decreased, and will decrease further over the coming years. The market now plays an increasingly significant role in determining what gets produced, where and how. At the same time, support within the CAP has started to place a greater emphasis on sustainability, the environment, and rural development, encouraging the provision of public or non-market goods.

One means of assisting this transformation of agricultural production policy into a rural development policy has been to adjust the balance of budget allocated to the two Pillars of the CAP. The balance of funding between these two Pillars is progressively being shifted – or 'modulated' – from Pillar 1 to programs within Pillar 2 that aim to a) improve the competitiveness of the agricultural and forestry sectors; b) maintain and enhance the environment and countryside; and c) improve the quality of life in rural areas (LEI, 2009).

The European Commission succeeded in implementing the modulation principle during Agenda 2000, an action program whose main objectives are to strengthen European policies and to give the European Union a new financial framework for the period 2000-2006 with a view to enlargement. Until the launching of Agenda 2000, in 1999, modulation had been voluntary, by up to 20% of first Pillar payments, and aimed at funding of specific rural development measures (Boulanger, 2008). The 2003 Mid Term Review of the Agenda 2000 rendered modulation compulsory. A compulsory modulation was introduced for all direct payments from the first Pillar, with a uniformed flat rate of 3% (in 2005), 4% (in 2006) and 5% of first Pillar payments (from 2007-2012). No modulation is applied to farmers that receive less than EUR 5000 a year. The 2009 ‘Health Check’ consolidated the 2003 reform. Adopted by the Council on 20 November 2008, it decided that modulation for direct payments would increase from 5% in 2008 to 10% of first Pillar payments in 2012. There are no rules specifying exactly what Member States may do with the funds provided by this extra modulation. The Commission only set allocation criteria by demanding that it should be spent within the framework of the rural development programs on the reinforcement of new measures, the so-called ‘new challenges’, which are linked to climate change, renewable energy, water management, biodiversity and accompanying measures for restructuring the dairy sector (in light of the milk quota abolishment in 2015) (EC, 2009b; EC, 2009c).

In Section 2.4.2, the spending of Health Check compulsory modulation will be evaluated for the Netherlands – the country we are most familiar with – using the policy objectives evaluation framework proposed in Section 2.3. The Netherlands has been chosen as subject for the case study mainly because of easy language accessibility of policy documents.

2.4.2 Application of the evaluation framework to a European case study: Evaluating the impact of the Health Check compulsory modulation in the Netherlands

A central theme for all rural development policies in the Netherlands is ‘strengthening the position of the Dutch agro-cluster in terms of competitiveness, market orientation, innovation and sustainability’. The extra funds generated through the Health Check decision contribute to this. In particular, the Dutch allocation of extra modulation funds is manifested around the central themes of innovation and long-term sustainable application. The expenditure focuses specifically at sustainable entrepreneurs, and exclude rural non-agricultural actors.

Until 2013, EUR 146 million will become available in the Netherlands because of the extra funding from the Health Check decision. Member States are expected to contribute at least 25% co-financing from national financial resources. Provincial councils work closely together to spend the additional resources, as they are jointly responsible for implementing and co-financing the extra funding. The government together with the provincial councils specified six spending targets, which are six main themes that are used to spend financial resources and that comply with the ‘new challenges’ as prescribed by the EU Commission (TK, 2009a). The existing schemes and regulations under the Dutch National Strategy for Rural Development 2007-2013 are used to spend the available budget.

For the policy evaluation, seven policy documents are consulted, selected because they record and refer to the six spending targets relevant to this case study. Table 2.2 gives an overview of the consulted documents and spending targets.

Table 2.2: Overview of consulted policy documents and corresponding spending targets

Policy documents	Spending targets
Uitvoeringsprogramma Biodiversiteit (LNV, 2009); Implementation programme for Biodiversity	Field margin management Enhancing environmental quality, reduction of environmental losses from agriculture
Vierde Nederlandse Actieprogramma betreffende de Nitraatrichtlijn (2010-2013) (TK, 2009c); Fourth Dutch Action Programme (2010-2013) concerning the Nitrate Directive	Improving water quality and water quantity management
Deltacommissie 2008 *'Samen werken met Water'* (Deltacommissie, 2008); Delta Committee report 2008	
Innovation agendas of various agricultural sectors such as innovation agenda dairy, intensive livestock (TK, 2009b)	Innovation of agriculture
Innovatieagenda Energie (EnergieTransitie, 2008); Energy Innovation Agenda	Renewable energy production
Monitor Schoon en Zuinig (Hanschke, 2008); national programme for renewable energy production	
Houtskoolschets Europees Landbouwbeleid 2020 (LNV, 2008); Dutch CAP 2020 Outlook	Highly valued areas

In the following subsections, each spending target will be briefly described and the allocated budget indicated for each individual target.

Field margin management

For field margin management, the government allocates EUR 30 million as a result of the extra compulsory modulation. With this extension, the government wants to strengthen biodiversity in agricultural areas and to compensate for the abolition of set-aside requirements. Farmers can be subsidized for maintaining two types of field margins with different aims: those aiming at protected species and those aiming at functional biodiversity.

Improving water quality and water quantity management

EUR 20 million is spent for a package of measures aiming at improving water quality, ecologically and chemically, and water quantity management. The emphasis is placed on remunerating countryside stewardship, land and water management services and encouraging sustainable investments. Biodiversity will be enhanced through creating transition zones between land and water and by creating ecological corridors.

Enhancing environmental quality, reduction of environmental losses from agriculture

A package of measures is created for the enhancement of environmental quality and further reduction of environmental losses from agriculture. In this way, damage to soil structure and emissions from phosphate, nitrate, heavy metals, ammonia, greenhouse gases or particle pollution are reduced. EUR 40 million is available for investment, and innovations and sustainable management of agricultural practices are encouraged. Examples of possible successful investments are precision agriculture in combination with manure processing, which results in savings in artificial fertilizer and fuel.

Innovation of agriculture

Encouragement of innovation to address the new challenges of climate change, water management, biodiversity and renewable energy is one of the key developments for maintaining a strong competitive position. Regional innovation initiatives are included, as long as they are focused on farmers and the new challenges. An amount of EUR 25 million is earmarked for this purpose, which is aimed at the primary agricultural sector. Innovations can include technical innovations as well as innovations in terms of processes, organization and human resources.

Renewable energy production

Agricultural-based renewable energy production is another challenge which will be addressed with the extra funding from Health Check modulation. Further development of biogas, the generation of knowledge on co-digestion of manure, turning waste heat into power and cogeneration are supported. Using waste from agriculture (such as beet leaf) and biomass from woodland, opportunities are provided for the synergy of landscape and nature objectives. For this package, an amount of EUR 10 million is set aside.

Furthermore, the government supports and promotes advisory activities on renewable energy, energy saving and greenhouse gas emission, thereby strengthening the development of renewable energy production.

Highly Valued Areas (LFA areas)

A remuneration system is created for stewardship services in Less-Favoured Areas (LFAs). These are areas with natural restrictions for farming and where farming contributes substantially to the preservation of such valuable landscapes or nature areas. EUR 10 million is available to ensure preservation of agricultural activities in these areas. Part of the budget will be used to solve problems with the designation and delineation of Natura 2000 areas, which experience difficulties from raised groundwater tables and ammonia and manure emissions from livestock farms.

Table 2.3: Results policy evaluation for spending EU Health Check compulsory modulation in the Netherlands.

Resilience criteria	Specifications	Spending targets						
		Field margin management	Improving water quality	Enhancing environmental quality	Innovation of agriculture	Renewable energy	LFA	Average: $\frac{\sum_{i=1}^{6} a_{ij}}{6}$
Diversity	Diversity of species, ecosystem types and crops	0/2	2/2	2/2	2/2	2/2	0/2	8/12
	Diversification of agricultural goods and services	0/2	2/2	0/2	1/2	0/2	0/2	3/12
	Diversity of ecosystem services types considered beneficial	0/2	2/2	0/2	1/2	0/2	0/2	3/12
Ecological variability	Adaptive management of rural ecosystem	1/2	2/2	0/2	0/2	0/2	0/2	3/12
Modularity	Multiple types of organizational structures and farm structures	0/2	0/2	0/2	2/2	2/2	1/2	5/12
	Compartmentalization of biodiversity in space, time or organizational structure to enhance the provision of ecosystem services	2/2	2/2	1/2	0/2	0/2	0/2	5/12
Acknowledging slow variables	Long term policy perspective	2/2	2/2	2/2	2/2	2/2	2/2	12/12
Tight feedbacks	Local supply and demand within the local food supply chain	0/2	2/2	0/2	2/2	2/2	2/2	8/12
	Local solutions to enhance the provision of ecosystem services	0/2	2/2	0/2	2/2	2/2	2/2	8/12
Social capital	Strong networks between rural stakeholders	0/2	2/2	0/2	0/2	2/2	2/2	6/12
Innovation	Experiments and new initiatives by rural stakeholders	0/2	1/2	1/2	2/2	2/2	0/2	6/12
Different levels of governance	Diversity in governmental structures and levels of execution	2/2	1/2	1/2	2/2	2/2	2/2	10/12
Ecosystem services	Costs for maintaining unpriced ecosystem services	0/2	2/2	0/2	0/2	0/2	0/2	2/12
Average: $\frac{\sum_{j=1}^{13} a_{ij}}{13}$		7/26	22/26	7/26	16/26	16/26	11/26	79/156

2.5 Main results case study

In Table 2.3 the criteria listed in Table 2.2 are used to evaluate the Health Check compulsory modulation in the Netherlands. All spending targets score well on the criteria ‘acknowledging slow variables’ criterion as they are all part of a larger policy framework which is constituted over a longer period. Also the ‘tight feedbacks’ and ‘different levels of governance’ criteria score well because of the high emphasis on local stakeholder participation among the spending targets. The lowest score is attained by ‘unpriced ecosystem services’. Apparently, it is difficult to develop policies that take into account unpriced services from which human welfare benefits.

The highest score on resilience was obtained by the ‘improving water quality’ spending target. This particular spending target considers intensive participation with local stakeholders in rural management, emphasizing countryside stewardship. Also the ‘highly valued areas’ spending target focuses on local stakeholder involvement through countryside stewardship, thereby encouraging the development of tight feedbacks and allowing for experiments and initiatives by rural stakeholders. The ‘improving water quality’ spending target is the only one focusing on unpriced ecosystem services, especially focusing on water regulation and water quality. Because of its attention to enhancing local stakeholder engagement, awareness is created for these unpriced ecosystem services. The lowest score was achieved by the ‘field margin management’ spending target, the main reason being the low score on the criteria of creating diversity and encouraging innovation, because of the focus on two specific field margin management types. Also within the ‘highly valued areas’ spending target, there is an emphasis towards preservation of specific landscape elements. leading also to a low score on diversity.

The ‘renewable energy’ spending target stimulates all types of regional and local initiatives aiming at efficient use of energy and innovative methods to produce energy. This spending target focuses on supporting individual projects (EnergieTransitie, 2008) and therefore has a high score on creating social capital and tight feedbacks. Through multiple governance structures coordinating the programme, the ‘different levels of governance’ criterion is met. Because the ‘innovation of agriculture’ spending target also focuses on multiple governance structures (i.e. on regional and local initiatives for maintaining biodiversity, renewable energy, water, etc.), there is some overlap between this spending target and that of ‘renewable energy’.

The ‘enhancing environmental quality’ spending target addresses specific policy measures to achieve objectives with respect to precision agriculture, particle pollution, nitrate, etc. Although the policy documents stress the importance of executing policy instruments at a local level, the documents make no reference to how this lower level execution should be managed (TK, 2009c).

Maximum scores were obtained for the ‘acknowledging slow variables’ and ‘different levels of governance’ criteria. The evaluated policy documents all show they are part of a long-term policy perspective and try to include different levels of governance in their decision-making strategy. Lowest scores are obtained for the ‘ecosystem services’ and ‘modularity’ criteria, the main reason being that the actual payment for ecosystem services has not been applied often in the policy measures. Additionally, for the ‘modularity’ criterion, not all spending targets refer to stimulating different organizational structures and farm structures. Nor to compartmentalization in their policy objectives.

When taking into account the overall results of the policy evaluation, it can be concluded that the spending targets have an average score of 79/156 (we denote by a_{ij}, the i-th row and the j-th column of matrix a) on the criteria for developing resilience. This outcome can be interpreted as an overall score and gives insight into the extent to which the policy objectives target implementing criteria for resilience in rural SESs in the respective program. The value of this score, and possibilities for future use, will be discussed in Section 2.6.

2.6 Conclusion and Discussion

The policy objectives evaluation framework proposed in this chapter, the like of which we have not found elsewhere in the literature, is a first attempt to facilitate the implementation of the results of scientific research on resilience into rural policy development. The framework signals to what extent aspects of resilience are incorporated in rural policy plans and indicates what the strengths and weaknesses of these plans are with respect to the proposed resilience criteria. The policy evaluation framework discussed in this chapter has its strengths and weaknesses. As the list of criteria provided by Walker and Salt (2006) was the only list covering a large number of aspects of the SES, further research is needed to improve the coherence and distinctiveness of this list. The criteria and specifications we have used so far are generic and abstract, and thus require further specification. We regard this as an advantage of our framework. Building in resilience is very much dependent on the political, economic, ecological and social contexts, and follows a pathway of collaborative learning rather than generic guidelines. To create greater convergence in policy objectives towards resilience development, more socio-economic research, ecological research and public debates regarding environmental values and farmers' contributions to these values will be required. The policy evaluation framework proposed in this chapter can provide a starting point for discussion. Therefore, we hope that our framework will be further developed in a variety of social-ecological systems at various levels on a political scale. Feeding back learning outcomes from these specific cases will contribute to a more general understanding of the significance of this framework for policy development.

Because the policy evaluation framework discussed in this chapter is limited to ex-ante evaluation of policy objectives, the impact of actual execution of the policy program falls outside our scope. The fact that the disturbance is unknown beforehand, implies that it is impossible to customize the policy in advance. Because we deal with ex-ante evaluation, we assume that rural policies can serve as a positive incentive for enhancing resilience in rural areas. However, once implemented, policies can also have a negative effect on an area's resilience. For example, for European rural SESs, policy programs aiming at increasing the resilience of farmers to sudden price disturbances in inputs and outputs through stimulating diversification of farm income sources could ultimately lead to lower resilience compared to specialized farms because of low economic performance through lack of markets and increased production costs. Therefore, there is a need to adjust the policy evaluation framework in such a way that it can be used for ex-post analysis as well. Downscaling the framework to the local level, distinguishing measurable indicators for policy impact analysis, evaluating policy efficiency, adjusting specifications, etc. are issues for future research that have to be dealt with when adjusting the evaluation framework presented in this chapter.

By using the list provided by Walker and Salt (2006), we focus on the key characteristics for resilient rural SESs. It can be concluded from the application of the framework to the case study that a quantitative approach to evaluate resilience in rural development policies is not appropriate for all suggested criteria. Especially the criteria related to networks and adaptive management are difficult to translate into measurable indicators. We have therefore chosen for a qualitative approach, to evaluate how a specific resilience criterion was met. Some criteria discussed in the framework proposed in this chapter are difficult and complex to monitor because they are not scaled to a time or spatial dimension. For example, the slow variables criterion was interpreted as 'policy with long-term perspective'. However, the definition of 'long-term' perspective remains vague. For the interpretation of 'tight feedbacks', the scaling of 'local' remains to be determined. Can a policy measure, designed on a regional or national governance level, but performed by local farmers be called a local solution? Or do we assume that local solutions must be developed bottom-up; based on farmers' own initiatives? Here, further development is necessary, e.g. by a more thorough elaboration of the individual criteria through quantitative indicators. Future work could include extending the policy evaluation framework by differentiating between quantitatively measurable criteria and qualitatively assessed criteria.

With respect to overlap and contradictions between the criteria for policy evaluation, Walker and Salt (2006) indicate that it cannot be claimed that these criteria are unique. Contradictions exist between the 'modularity' and 'tight feedbacks' criteria. Where modularity focuses on the compartmentalization of the system into separate modules, tight feedbacks focus on the internal feedback loops within one module. Overlap also exists between the 'tight feedbacks' and 'social capital' criteria. Where tight feedbacks focus on the feedback loops between ecosystem and socio-economic system characteristics within individual modules, social capital tries to give insights into the characteristics of the interactions and networks in the socio-economic system. For future development of the framework, more effort should be given to demonstrating the distinctiveness of the individual criteria.

This brings us to the overall result of Table 2.3, which gives an overview of how the policy programmes meet the criteria for developing resilience. Apparently, more than half of the maximum score (79/156) is achieved in the case study discussed. First of all, we have to underline that this score should be interpreted as a relative score. Because the framework is based on system characteristics, the score does not inform about trends in environmental, social or economic values. We believe there are interesting future applications in comparing different policy programmes on the basis of these scores and analyse relationships between scores on system characteristics and the long-term variation in sustainability values. The score could serve as input for policy decision-making processes, and is part of a process towards embedding resilience in rural policy making. In this chapter, the weightings of the criteria were kept equal, but policy makers may decide to weight criteria differently if they want to evaluate a policy programme with our framework. We advocate attempts to use this framework for rural decision making on a local level. Local stakeholders can then decide on the weightings of the individual criteria and thereby tailor the decision making to their own preferences.

3. Rural landscapes in turbulent times: A spatially explicit agent-based model for assessing the impact of agricultural policies

Schouten, M., Polman, N., Westerhof, E., Kuhlman, T., 2012. Rural landscapes in turbulent times: a spatially explicit agent-based model for assessing the impact of agricultural policies in: Teglio, A., Alfarano, S., Camacho-Cuena, E., Ginés-Vilar, M. (Eds.), Lecture Notes in Economics and Mathematical Systems. Managing Market Complexity. The Approach of Artificial Economics. Springer, Castellón, Spain, p. 195-206.

Abstract

This chapter presents a spatially explicit rural agent-based model which has been developed to assess how agricultural policy interventions, market dynamics and environmental change affect heterogeneous farm agents, their land use and the landscape of which they are part. This model moves beyond current literature by modelling market transactions among agents that are heterogeneous with respect to their economic and environmental characteristics within their spatially explicit landscape. The spatially explicit landscape is described by parcel size, natural, environmental and agricultural quality, shape, type of land use, intensity of use and distance to the homestead. The model is presented using the Overview, Design concepts, and Details (ODD) protocol. Modelling features are demonstrated by evaluating two different land market implementations which are based on auction mechanisms. We also explore how economic indicators change as the relative market power of buyers and sellers change, by moving from a buyers to a sellers' market and vice versa.

3.1 Introduction

Rural landscapes are expressions of the interface between human societies and their natural environment. They are highly diverse because of both natural and cultural features, and their history is expressed in their spatial patterns. All landscapes are subject to processes of change, but because of the great value we attach to the landscape in densely populated areas, we like to steer such changes through policies (Pedroli et al., 2007). Explaining and predicting behaviour of land managers is useful to policy makers aiming at preserving the rural landscape. In this chapter, we explore the impact of agricultural policy interventions on farmers' investment decisions, in particular on whether they acquire more land or divest themselves of it. In order to deduce the effects of such decisions on the landscape, we made them spatially explicit, i.e. we map agricultural parcels and examine which parcels will be transferred by whom to whom. Farmers attract and supply land on the land market, and the decision of one will affect others and land use intensity. They are heterogeneous agents because their decisions will depend on the size, type and prospects of their farm and preferences of the farmers. All this strongly points to the need for a spatially specific, agent-based land market model, and this is what we present here.

Agent-based models (ABMs) within the specific agricultural policy context were pioneered by Balmann (1997) with the Agricultural Policy Simulator (AgriPoliS); Jager et al. (2002) who explored how overharvesting affects the relationships between human activities and natural resources and Berger (2001), Happe et al. (2009), Lobianco and Esposti (2010) and Schreinemachers and Berger (2011) who evaluate the way agricultural policy intervention affects a heterogeneous population of farm households and their resources. The model presented in this chapter contributes to literature by looking closely at how agents embedded in rural landscapes adapt to agricultural policy interventions and change the rural landscape in this process and how this can inform governance processes in rural development.

Our model moves beyond previous work in several respects. First, farm agents and their respective parcels are modelled in detail, including heterogeneity in parcel size, quality, shape and distance to the homestead. Second, to explore the impact of policy interventions on land market outcomes, we explicitly model a land-auction mechanism that takes into account multiple parcels with multiple characteristics at once. Third, we are able to experiment with the division of gains from trade depending on whether there is a buyers' or a sellers' market, and give insight into the consequences of the revenue from trading on the allocation of land.

We proceed as follows. First, the spatially explicit rural agent-based model (SERA) is introduced. The structure, concepts and details of the model are presented using the ODD (Overview, Design concepts and Details) protocol (Grimm et al., 2006; Grimm et al., 2010). Secondly, we present experiments that compare the market mechanism used in SERA with a more conventional market mechanism and then explore the implications of differentiating in relative market power of buyers and sellers on the land market through experimenting with different levels of buyer/seller surplus. Finally, conclusions are drawn and the contribution of SERA to existing literature on agent-based models for agricultural policy analysis, as well as future directions for the model is discussed.

3.2 Spatially Explicit Rural Agent-based model (SERA)

3.2.1 Purpose

The core of the model discussed in this chapter is the understanding and modelling of an agent-based system for the purpose of agricultural policy assessment while simulating the agents and their corresponding landscape in a spatially explicit way. The model establishes a virtual world of a rural region and comprises a large number of individually acting farms that operate in this region, as well as farms interacting with each other and with parts of their environment. The model implements an abstract region, that can be initialized with empirical data on individual farms and existing agricultural spatial structures. In the following, we present a description of the single entities of the model and describe their relationships.

3.2.2 State variables and scales

Within SERA, the following hierarchical levels can be distinguished:

- *Farm agents* representing dairy farm households, with as many agents modelled as there are dairy farm households in reality. State variables of the agents include the location of the agent’s farmstead, the location of their fields, the individual household composition (age, successor), available resources such as cash, livestock, nitrogen balance and feed balance of the farm.
- *Spatially explicit farm land* representing all spatially explicit parcels as well as their current land use. For each parcel the size, shape and current land use is known and the distance to the homestead is calculated. Also, possibilities for agri-environmental schemes (AESs), which is an example of a government attempt to influence farmer’s decisions to enhance levels of biodiversity on farmland are known (Whittingham, 2011). For each parcel, the nitrogen production by grazing cows is calculated, as well as the amount of feed produced on the parcel (differentiated by soil quality) and its contribution to the total feed production of the farm. For illustrative purposes in this chapter, the land market for dairy farmers is modelled as a closed market which means that only dairy farmers participate.
- *Regional land market:* Where the auctioneer describes the mediation between traders of land on the regional land market.

Furthermore, all other landscape elements such as large creeks, nature conservation areas, and nearby towns are modelled and can be included into the spatial extent of the system. SERA can be parameterized at various spatial scales, ranging from a small rural community to a province, depending on model purpose and data availability. Government interventions are treated as external in the model. Table 3.1 gives a summary of the parameters of SERA.

Table 3.1: Summary of model parameters

Classes	Parameter	Unit of analysis
Parcel grass production	Dry matter production grass GOOD	kg dm
	Dry matter production grass MEDIUM	kg dm
	Dry matter production grass POOR	kg dm
	Feed sell price (percentage of buy price)	percentage
	Workability coefficient grassland	percentage
	Mineralisation grassland	kg N
	Leaching coefficient grassland	percentage
	Fertilizer application grassland	kg N
Parcel maize production	Fertilizer application maize land	kg N
	Feed production maize	kJ
	Nitrogen application maize	kg N
	Fertilizer price	euro/kg
Farm agent	Maximum number of cows per hectare	number
	Milk production per cow	kg milk
	Minimum ask price as percentage of expectation	percentage
	Feed requirements per dairy cow	kJ
	Nitrogen buy price (as percentage of sell price)	percentage
	Nitrogen production per cow	kg N
	Fixed transport costs	euro/ha
	Transport costs coefficient	euro/km
Agri-environment scheme	AES contract length	years
	AES nitrogen allowance	kg N
	AES subsidy	euro/ha
	AES fixed transport costs	euro/ha
	AES transport costs coefficient	euro/km
Parcel quality	Use parcel quality	boolean
	Use Reilly index	boolean

3.2.3 Process overview and scheduling

The model proceeds in annual time steps. Figure 3.1 depicts the organization of the model framework at the program level by providing the conceptual class diagram of SERA with the main classes and their relations.

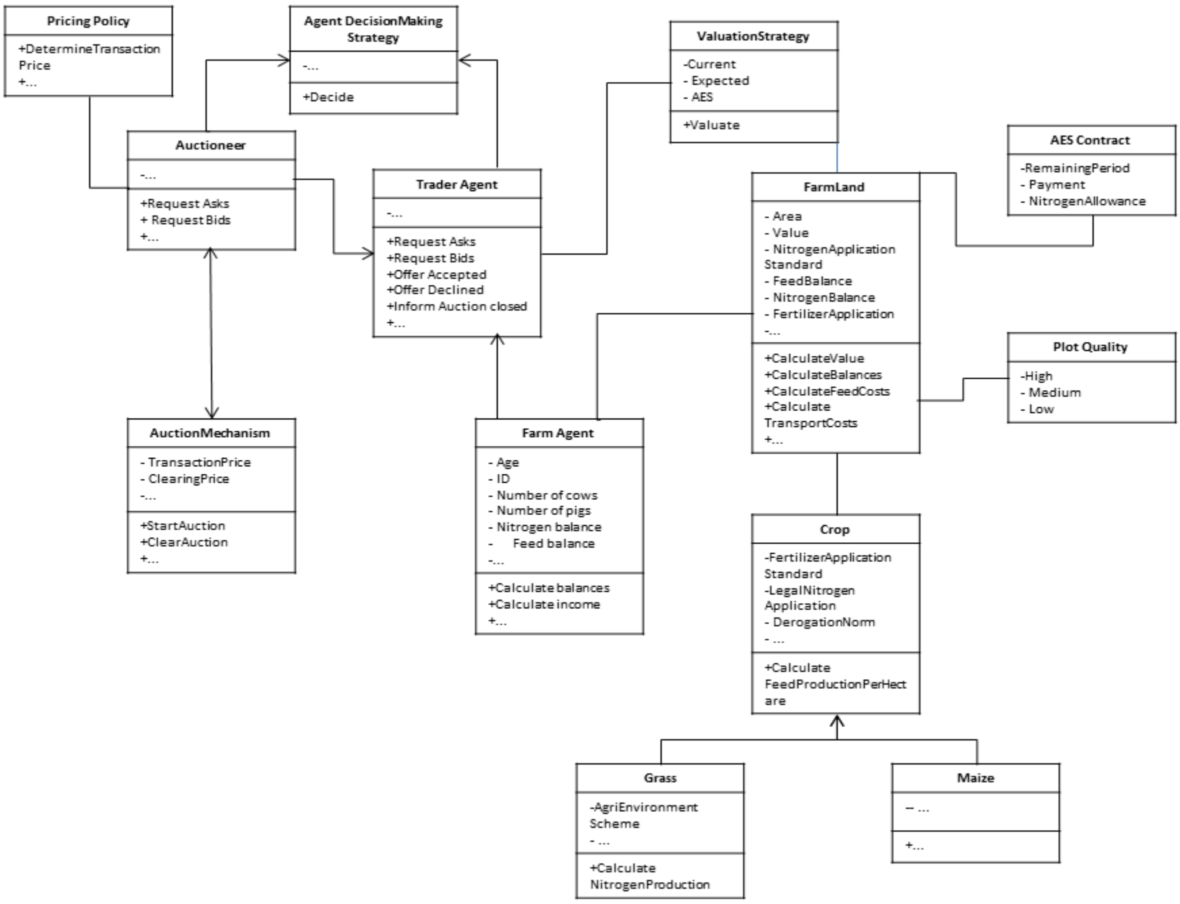

Figure 3.1: UML class diagram of SERA: program classes with main attributes and relations

Figure 3.1 shows that two types of agents are distinguished, the *Trader Agent* and the *Auctioneer*. *Trader Agent* describes all agent that can be traders, and that wish to trade parcels of land. Farmers in the model are such trader agents. Decision making strategies are described in the class *DecisionMakingStrategy*. Every *TraderAgent* has a *ValuationStrategy* which is used to determine the valuation for a parcel. The resulting value of a parcel is expressed by the class *ValuationStrategy*. Individual parcels are represented by the class *FarmLand*, that holds all information on the parcels that belong to the farms. Farmlands hold crops (class *Crop*), and a certain quality (emuneration *PlotQuality*). Two implementations currently exist: *Maize* and *Grass*. Farmlands can also hold agri-environmental contracts (class *AES Contract*). The other agent currently in the model is the *Auctioneer*. The *Auctioneer* is the mediator between traders. The *Auctioneer* requests traders to make offers to either express their willingness to buy or sell a good. The *Auctioneer* makes use of a mechanism to match bids and asks to clear the market. This is represented by the class

AuctionMechanism. Currently, the model contains two types of mechanisms to clear the market in a number of iterations. It presumes that multiple buyers and sellers are present and the parcels traded are heterogeneous (characterised by multiple attributes). An extensive discussion of the market mechanism used in this model can be found in Section 3.3 where we compare different mechanisms with selected output variables.

The main logical steps are as follows. The model consists of an *initialization phase* in which data is conditioned for use in the model; a *simulation phase* in which farm incomes are calculated and land is distributed among farmers (land auction mechanism), and an *output phase*. The *initialization module* contains exogenous agricultural census data. The attributes on farm level are the farm structure, given in age, type of farm, size and number of owned parcels. At parcel level, attributes are soil quality and land use. At landscape level, attributes are number of farms in the region, spatial landscape characteristics (i.e. rivers, roads, nature conservation areas, nearby towns), size and distance. Within the simulation phase, each farm agent is equipped with a behavioral model that guides decisions and keeps track of the agent's internal state described by attributes such as age, location and size. According to their behavioral model, the individual farm agents evolve subject to their state of attributes and to changes in their environment (see Appendix 3A for overview of farm agent behavioral model[2]).

The results of the farm module are merged in the land market module. A detailed description of the market module for perpetual land lease is given in Section 3.2.6. Finally, the function of the output module is the conditioning of the model results for the next simulation period. Results on farm level as well as on the regional level are used for updating farm attributes and regional attributes in the next period.

3.2.4 Design concepts

Emergence: Land use patterns emerge in response to farm agent behaviour on the land market. Also changes to neighbouring nature areas as well as policy changes and market disturbances result in emerging behaviour of land use patterns.

Adaptation: Farm agents adjust their resource management (land, nature, livestock) in response to transactions on the land market, policy changes and changing market conditions. For instance, if output prices, such as milk prices, show a large volatility over a certain period, farm agents can chose for alternative income strategies by contracting agri-environment schemes.

Prediction: Agents form expectations about market prices based on past experience, following the theory of adaptive expectations. Agents revise their expectations with respect to output prices periodically by calculating expected prices for land which are used in the decision making process (following Kellermann et al., 2007). They are used in the form of a weighted moving average of the prices in the past periods.

[2] For a full description of SERA see http://www.wageningenur.nl/en/Expertise-Services/Chair-groups/Social-Sciences/Agricultural-Economics-and-Rural-Policy-Group/Publications/SERA-model.htm

Agent-agent interaction: Interactions between agents takes place on the land market. Farm growth in agriculture is often binding to the availability of land, either as direct production input (e.g. for crop production) or indirect (e.g. if animal production is tied to the availability of land for manure disposal). Land markets are used as a platform to allocate land (Kellermann et al., 2008). An extensive elaboration on the use of land markets in SERA is given in Section 3.2.6 and 3.2.

Agent-environment interaction: The interactions between farm agent decision making and agro-ecology is represented by grassland yields, maize land yields (feed balance) and manure disposal (nutrient balance) in SERA. Grassland yields and maize yields are constrained by the yield potential which captures land quality factors during simulation. They are also constrained by the available nutrients. This means that whenever the nutrient balance on farm level shows a surplus, farmers will use all the legally permitted nutrients on their land and will have to dispose the remainder of their manure on the external market. Agent decisions can also have a direct impact on the environment through applying optional agricultural nature conservation on their parcels.

Stochasticity: Stochasticity is used in one of the two implemented auction mechanisms to simulate imperfect information of potential suppliers and attractors of land on the land market. Furthermore, random numbers can be combined with probabilities in SERA to simulate trade-offs in the farm agent decision making process.

3.2.5 Initialization and input data

At the start of each run, initial values of the state variables as well as the farm agents and their environment are uploaded. As its basis, SERA uses Agricultural Census data from the Dutch Ministry of Economic Affairs. Data on biophysical components and institutional aspects of land ownerships stems from GIS-cadastral maps with current land use, ownership and soil quality.

SERA-input data are organized in two modules. First of all, farm survey data is used to characterize the individual agents, their resource endowments, and the size of their farm. Then, spatial data is used to locate the farmsteads, the agricultural parcels, the nature conservation areas, the potential parcels for agri-environmental schemes, the current land use and soil quality.

3.2.6 Submodels

Farm agent decision making: At the core of SERA is the valuation module that simulates the decision making of individual farm households. Within each time step the resource land as well as expectations about land market prices are updated. Because SERA deals with parcels that are heterogeneous in size, quality and shape, the model does not deal with a conventional farm optimization problem. We have created a constrained optimization, in which farmers take into account these parcel characteristics. In each period farm agents calculate the operational profit for both their grassland and maize land parcels, as well as for new parcels available on the land market. For each parcel revenues are calculated (i.e. revenue from milk production, feed production, manure disposal and subsidies) and a set of costs (i.e. transport costs, manure disposal costs, costs for buying feed etc.) is subtracted. What remains are the gross margins per parcel. The farm agent compares the operational profits for the offered parcels and has the opportunity to bid on offered parcels whenever their bid price is higher than the reserve price. Next to bidding on the land market for new parcels, the farm agent makes a trade-off between three types of land use for the parcels that are in use: conventional grassland and maize land, and possibilities for agri-environmental contracting. Whenever an AES is chosen, this type of land use remains on the parcel during the contract period. The following tradeoffs can be summarized:

- Parcel has no possibility of AES contracting. Choice is made either to offer the parcel to the land market due to high opportunity costs, or maintain conventional farming.
- Parcel is not yet contracted, but has possibility for AES. Farm agent makes a tradeoff between conventional farming, AESs, or offering the parcel to the land market because of high opportunity costs.
- Parcel is contracted with AES, but contract expires. Choice whether to extend contract, switch to conventional farming or offer the parcel to the land market due to high opportunity costs.

For each tradeoff the expectation price (Section 3.2.4) is included in the determination. Whenever a farm agent choses an AES, an extra restriction on manure and fertilizer application is applied to the parcel which affects the parcels' contribution to the operational profit.

Biophysical modules: SERA simulates resource dynamics and crop yields in the following way. First, the decision-making module simulates land use based on expected conditions (soil quality and expectation prices). Then actual resource conditions and actual crop yields are calculated for each parcel. Finally, the actual crop yield is transferred back to the agent decision module where it is evaluated and used to update the expectations.

The real-world landscape is represented by actual parcels, heterogeneous in size, quality and land use. Spatial information was organized in layers, including the location of the parels, the location of the farm steads and parcel and soil properties. In this chapter, we distinguish between four types of land, namely conventional grassland, grassland with possibilities for AES, maize land and nature conservation areas.

Informed single auction market mechanism: Agents in SERA interact indirectly by competing on a land market. The land market is the central interaction institution between agents in SERA and is fully endogenous in the model. There is a broad range of applications of land market mechanisms within agent-based models available for social sciences (see Parker et al., 2003; Parker and Filatova, 2008; Filatova et al., 2011; Kellermann et al., 2008; Magliocca et al., 2011). Our approach has in common with other approaches that land allocation is modelled through an auction mechanism in which competition for land is based on a defined bidding process and a set of rules for price determination and matching of asks and bids. However, it differs from existing approaches in that farm agents are informed in advance whenever multiple parcels are offered simultaneously. They are informed on several attributes of the parcel: soil quality, size, current land use and distance to the homestead. In SERA, farm agents extend their hectare base exclusively so called perpetual lease contracts. This implies that the farm agent is free to offer the parcel again to the land market or remain farming after each simulation period. When SERA is run, available perpetual lease parcels stem from two sources: one is that farms offer their land to the market due to high opportunity costs, the second one is retirement of farmers when they reach the age of 65 and do not have a successor.

The informed single auction market mechanism of SERA proceeds as follows. At the start of each auction, the auctioneer informs the traders that the auction is open. Based on the outcome of the farm agent decision making (does the agent wants to offer or attract parcels?), traders can respond by expressing interest in the auction. Next, the auctioneer requests all interested agents to provide the parcels they would like to offer with a related reserve price for these parcels. This reserve price is determined by the valuation strategy the agent is applying. Once all asks have been identified, the auctioneer requests the interested agents to provide bids for the parcels on offer. An interested farm agent evaluates all available parcels and is allowed to create one bid, for the asks that he or she values the most. Again, this is decided by the farm agent's decision making strategy.

After all bids have been collected, the informed single auction mechanism matches bids and asks based on creation of the largest surplus (difference between bid price and reserve price). The auctioneer will inform the traders involved in a transaction, who then complete the transaction and are asked to provide new asks, or can update or retract their asks in the auction, based on their valuation and decision making rules. If there are still unaccepted asks left after the matching process, a new cycle of iteration of the auction is started, in which remaining participating agents are again asked to provide a bid for one of the remaining asks. The process continues until there are no asks left, or no more bids are made. The auctioneer will then inform all interested traders that the auction is closed. In order to calculate the transaction prices for all matched bids in the auction, the auctioneer uses a pricing policy in which the surplus is equally shared ($k=0.5$). In Section 3.3 we discuss what the effects are of changes in this relative market power of buyer and sellers on the allocation of available parcels.

3.3 Implementation and selected simulation results

The model described in Section 3.2 has been implemented in REPAST. The software code of this model is written in the object-oriented programming language Java, using the open-source agent-based modelling framework *Recursive Porous Agent Simulation Toolkit Symphony (REPAST)*. We initialized the model for the agricultural region Winterswijk located in the eastern part of the Netherlands. This region covers an area of approximately 22,000 ha, and 66% of the agricultural holdings are dairy farms. For model initialization 206 individual dairy farms are distinguished, all of which are taken from the Agricultural Census (reference year 2008). In the initialization the model uses ownership, size and distance to farmstead for every single parcel. GIS-maps on land use and soil quality are used to integrate the production characteristics of individual parcels in the model.

3.3.1 Comparing two auction mechanisms

Using the case study Winterswijk, we compare our informed single auction mechanism with an iterative random single auction mechanism. For both auctions we assume that farm agents do not have the possibility to bid for several parcels simultaneously. For the random single auction mechanism we assume that parcels are traded in an iterative auction where one parcel at the time is offered. In this scenario the auctioneer picks one free parcel randomly and offers this parcel to all farms. Afterwards every farm formulates a bid for the offered parcel. The auctioneer collects all bids and the parcel is allocated via a first-price auction. Figure 3.2 shows the index in percentages for total operational profit (€50 million, revenues – variable costs= 100%) for the informed single auction, the random single auction, compared with a base line scenario with no trade for a simulation period of 30 ticks.

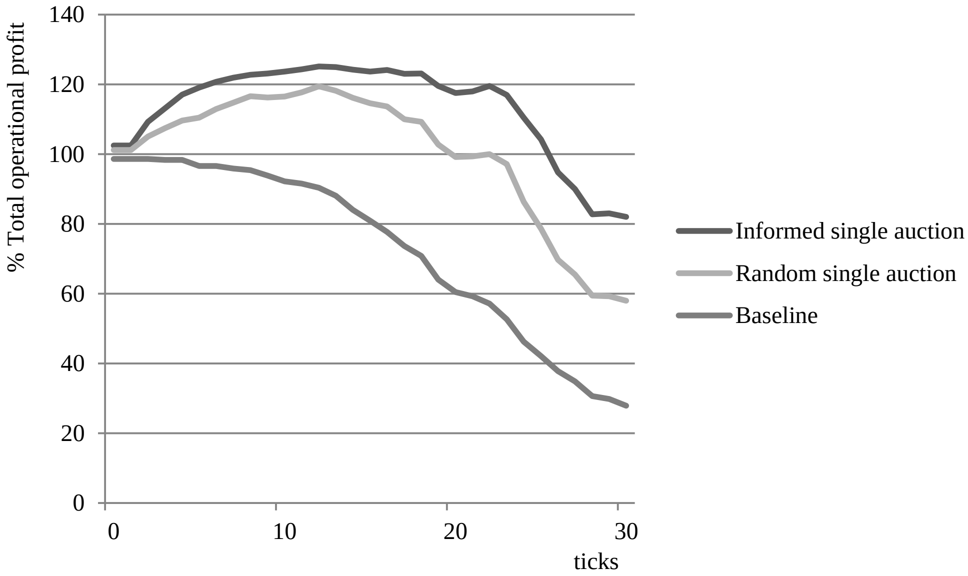

Figure 3.2: Total operational profit for two auction mechanisms and a baseline with no trade

Figure 3.2 shows that both market mechanisms result in higher operating profits than in a situation with no trade (baseline). The three scenarios show a decreasing trend because the number of farms decreases over time, which is a result of a lack of successors in the case study area. The random single auction mechanism results in a less effective allocation comparing to the informed single auction mechanism which can be seen through the % lower operational profit generated. The random single auction has an obvious disadvantage: by picking a parcel randomly and calculating a bid for this specific parcel we imply that a farm agent is not aware of its most valuable parcel, which could be more suitable (in terms of distance to the homestead, size, quality or land use) and hence more valuable for the farm agent.

3.3.2 Experimenting with buyer and seller surplus

In this section we focus on the effect of differentiation of relative market power of buyers and sellers (see e.g. Filatova et al., 2009) on the land market. After all bids have been collected, the auction mechanism matches bids and asks based on creation of the largest surplus (difference between bid price and reserve price). The share of the surplus allocated to buyer or seller can be explained by market power. We compare a pricing policy in which the bidder with the highest valuation receives the parcel by the price of his bid, by which we mimic a sellers' market, with a buyers' market meaning that the transaction price is equal to the reserve price of the land owner. Simulation results using the informed auction mechanism show that the buyers' market scenario affects the expectation prices of the farm agents resulting in a higher average transaction price when compared with the sellers' market scenario. The higher transaction price results in a higher willingness of farmers to offer parcels to the land market. If the supplied land has a higher valuation than the reserve price, land is allocated more effectively. Whenever the pricing policy would not have been implemented, these parcels would not have been offered in the first place. In this situation supply creates its own demand.

3.4 Conclusion

This chapter shows how the use of spatially explicit agent-based models can contribute to a better understanding of rural landscape dynamics, and the role of individual decision-making for landscape management. The strength of SERA is in the combination of economic and environmental heterogeneity among agents; capturing interactions between agents; and facilitating the combination with spatial modules simulating environmental dynamics. With regard to spatial explicitness, SERA is unique among integrated models of agricultural systems because of combining spatially explicit landscapes with microeconomic valuation of land through agents. By explicitly modelling consequences of market and policy changes, SERA contributes to developing more effective policies with respect to environmental conditions. These conditions are relevant for the EU Common Agricultural Policy and EU Water Framework Directive.

SERA also reveals the results of two different land market auctions on the spatial configuration in the rural landscape. Two land auction mechanisms are compared: an informed single auction mechanism which differs from existing approaches in that farm agents are informed in advance whenever multiple parcels are offered simultaneously. They are informed on several attributes of the parcel: soil quality, size, current land use and distance to the homestead and a random single auction in which the auctioneer picks one free parcel randomly and offers this parcel to all farms. Results show that the informed single auction in which farm agents are informed beforehand about the parcels that are offered, results in a more efficient allocation when comparing to a random scenario in which this information is lacking. Experiments with buyer and seller surplus show that the buyers' market scenario affects the expectation prices of the farm agents resulting in a higher average transaction price when compared with the sellers' market scenario, ultimately leading to a more efficient allocation.

Nevertheless, some caveats of the model exist with regard to the farm agents behaviour in the model. A caveat is that potential public and private transaction costs of schemes (see Mettepenningen et al., 2011) are not taken into account. With regard to the farm agents behaviour, their behaviour is limitedly rational, meaning that the decision making process of the farm agent is path dependent, and not globally optimizing. Another caveat is that investment activities as well as off-farm labour activities are not included in the model. Also a financial module, in which a farm can balance short- and long-term liquidity shortages and credits as well as investments in liquid capital and machinery, is not taken into account. Another valuable model extension is the explicit inclusion of cognitive, institutional and social processes. For example the inclusion of cooperation among farmers in social networks can be a valuable extension of the model.

Appendix 3A: Behavioural foundation dairy farm agents in SERA

This appendix describes the dairy farm agent's behaviour and the dairy farm agent's actions in SERA, which are used in Chapter 3, 4, 5 and 6 of this thesis. Two reference years were used for input data: 2008 for Chapters 3,4 and 5, and reference year 2010 for Chapter 6 (both Agricultural Census and GIS-data). Reference year 2008 is used throughout this Appendix.

The dairy farm agents' objective is to attain the highest possible operational farm income, given the information the dairy farm agent has. Although no explicit linear optimization problem is used in SERA because of heterogeneous parcels used, the farm agents' objective function can be expressed in the following way: Operational dairy farm income is based on the sum of the contribution of each individual parcel (i) and crops grown (j) (either grass or maize) on land controlled by the farm agent, based on the following function (1):

$$Y_{farm}^{dairy} = \sum_{i=1}^{n} Y_{ij}$$

For each parcel the contribution to the farm income (Y_{ij}) is calculated based on the following function

$$Y_{ij}\ (DI_i, S_i\ , TRC_i, MAR_i, FC_i, FB_i, p_{milk}\, p_j, p_{manureapply/dispose}, p_{fertilizer}) \tag{2}$$

with

$$Y_{ij}\ = DI_i + S_i\ + MAR_i - TRC_i - FC_i - FB_i \tag{3}$$

s.t.

Table 3A.1 gives an overview of the main parameters in the dairy farm model

Table 3A.1: Main model parameters dairy farm agent

Description	Unit of Analysis	Parameter
Dairy income on parcel *i*	Kg/parcel	DI_i
Fertilizer costs on parcel *i*	Euro/ kg N	FC_i
Manure application revenue (or costs) for parcel *i*	Euro/kg N	MAR_i
Legal nitrogen application norm	N kg/ha	N_{legal}
Nitrogen supply according to legal norms	N kg/ha	NS_{ij}
Nitrogen supply realized	N kg/ha	NS_{ij}^{real}
Nitrogen deposition due to grazing	N kg/ha	D_i
Nitrogen leaching	N kg/ha	L_{ij}

Transport costs depending on parcel *i*	Euro/ha	TRC_i
Transport costs for AES parcel	Euro/ha	TRC_i^{nature}
Milk production per cow	Kg/cow	$qmilk$
Nitrogen production per cow	N kg/cow	NP
Nitrogen production per parcel *i*	N kg/parcel	NP_{ij}
Fertilizer application for two crops (grass or maize) *j*	N kg/ha	FU_j
Mineralisation grassland	N kg/ha	M_i
Yield losses for the parcel *i*	% point	$yieldloss_i$
Milkprice	Euro/kg	p_{milk}
Workability coefficient grassland	%	$work_{grass}$
Leaching coefficient grassland	%	$leach_{grass}$
NEL (feed) requirements per dairy cow	NEL/cow	NEL
AES subsidy for parcel *i*	Euro/ha	S_i
AES contract length	year	6
Nitrogen availability for parcel *i* with crop *j*	N kg/ha	NA_{ij}
Nitrogen uptake for parcel *i* with crop *j*	N kg/ha	NU_{ij}
Dry matter production grassland	DM/ha	DM_{ij}
Nett energy for lactation	NEL kJ/kg	NEL
Dry matter production per parcel *i*, expressed in NEL	NEL kJ/year	$DMNEL_{ij}$
Feed requirements grazing cows on parcel *i*	NEL kJ/kg	TFR_{ij}
Fertilizer costs on parcel *i* with crop *j*	Euro/ kg N	FC_{ij}
Fertilizer price	Euro/kg N	p_{fert}
Total feed bought/sold	NEL kJ	TFB_{ij}
Feed production crop *j* (maize)	NEL	$yield_j$
Fertilizer application crop *j* (maize)	N kg/ha	FA_j
Maximum number of cows per hectare	Cows/ha	r_{cow}

Parcels revenue from dairy production activities

The parcels income from dairy production (DI_i) is calculated as the sum of number of cows per hectare, known as the cow-ratio (r_{cow}), which is set at the initial level, times the size of the parcel in hectares ($parcel_{ij}$), times the average milk production per cow ($qmilk$) which is set at 7875 liter/cow/year (see CBS, 2009), times the milk price (p_{milk}). The milk price is given in the model at a rate of 0.31 euro/liter milk (CBS, 2009). In the model is a possibility to fluctuate this level.

$$DI_i = \sum (r_{cow} \cdot parcel_{ij} \cdot qmilk \cdot p_{milk}) \tag{4}$$

Nitrogen production

The nitrogen produced by dairy cows on the parcel (NP_{ij}) is calculated as the sum of nitrogen production per cow (NP) (115 kg N/cow/year, see CBS, 2009) times the cow-ratio (r_{cow}), times the size of the parcel in hectares ($parcel_{ij}$).

$$NP_{ij} = \sum NP \cdot r_{cow} \cdot parcel_{ij} \tag{5}$$

At the farm level nitrogen availability for grassland is calculated, where the nitrogen application of maize is subtracted. In this way a nitrogen balance is created at farm level. The relation between nitrogen application and feed production per ha per year is adapted from Middelkoop and Aarts (1991), Van de Ven (1992), Groeneveld et al. (1998), Groeneveld et al. (2001), and Peerlings and Polman (2008). The following nitrogen supply, nitrogen leach, nitrogen availability, nitrogen uptake and dry matter yield per parcel were calculated. The legal limits of the Dutch Ministry of Economic Affairs prescribe that nitrogen can be applied to the parcel up to a maximum of 250 kg N/ha (N_{legal}) for manure from livestock.

Here derogation is taken into account in the model: farm agents are allowed to apply 250 kg N/ha on their parcels whenever >70% of their farm is grassland. Whenever they do not comply to this obligation, the legal norm is decreased to 170 kg N/ha. The nitrogen supply (NS_{ij}) which has to fulfill the legal norms is calculated as *legal supply=manure.* Only transportable manure is assumed to be produced by the livestock.

But, the amount of N available for the grass is higher, NS_{ij}^{real} due to mineralization and deposition. The nitrogen supply (NS_{ij}^{real}) is calculated as *supply=manure+fertilizer+deposition+mineralisation.* We assume mineralization (M_i; process in which N is released from organic matter and becomes available for uptake by plants) is 250 kg N/ha, we assume deposition (D_i; N deposited by cattle during grazing) is 50 kg N/ha. A workability coefficient of 100% is assumed for the use of fertilizer FU_j, which is now set at 35 (Aarts, 1995, 1996, 2000).

The nitrogen supply (NS_{p_i}) which is used for the legal limits norm, set by the Dutch Ministry of Economic Affairs is:

$$NS_{ij} = parcel_{ij} \cdot NP_{ij} \leq N_{legal} \tag{6}$$

The nitrogen supply which is used to calculate the availability for grass later on (NS_{ij}^{real}), is calculated as:

$$NS_{ij}^{real} = parcel_{ij}(FU_j + M_i + D_i) + NP_{ij} \tag{7}$$

Not all supplied N will be available for grass because of N leaching (L_{ij}). The fraction of nitrogen supply that is leached is calculated using the following function:

$$L_{ij} = 15 + 0.32(NS_{ij}^{real} - 300) \tag{8}$$

Available N (NA_{ij}) at the parcel level can then be derived as follows:

$$NA_{ij} = NS_{ij}^{real} - L_{ij} \tag{9}$$

Only part of the N from available N is taken up by the sward. Uptake N/ha (NU_{ij}) is calculated as

$$NU_{ij} = \frac{(-(\alpha_b + NA_{ij}) + ((\alpha_b + NA_{ij})^2 - 4\alpha_a \alpha_c NA_{ij})^{0.5}}{-2\alpha_a} \tag{10}$$

Where α_a is a constant (1.14), α_b is the ratio α_b / α_c $(= 1.176 \cdot \alpha_c)$, α_c is the horizontal asymptote that is 11.85 per cent above the maximum N uptake per parcel.

Feed production

The dry matter yield of grass per parcel is expressed in tons of DM. The DM production depends on the N uptake of grass:

$$DM_{ij} = \frac{(-(\beta_b + NU_{ij)} + ((\beta_b + NU_{ij})^2 - 4\beta_a \beta_c NU_{ij})^{0.5}}{-2\beta_a} \tag{11}$$

Where DM is DM yield per parcel, β_a is a constant (19.88), β_b is 21.6$\cdot \beta_c$, β_c is 1.078$\cdot$ Max DM production. Maximum DM production is derived from a questionnaire by Peerlings and Polman (2008) and is based on the subjective judgments of individual farmers.

The net energy for lactation (NEL) is the energy value of forage needed by dairy cows expressed in NEL kJ/kg DM and is depending on grazing, according to:

$$NEL = (\gamma_0 + \gamma_1 NU_{ij} + \gamma_2 NU_{ij})^2 \tag{12}$$

Where γ_0 is 5947.932, γ_1 is 15.0628 and γ_2 is -0.020439 (see Peerlings and Polman, 2008).

$$DMNEL_{ij} = \frac{NEL \cdot DM_{ij}}{\delta} \tag{13}$$

The DM ($DMNEL_{ij}$) produced per parcel, expressed in NEL kJ, per year is calculated by multiplying the NEL in kJ per kg DM by DM production per parcel divided by a production coefficient (δ =6.9). This coefficient is set at DM production to be medium quality grassland, given the questionnaire of Peerlings and Polman (2008).

Feed requirements grazing dairy cows

To calculate the feed requirements of the grazing dairy cows on the parcel, the total net energy requirements for lactation (TFR_{ij}) of the herd should be calculated.

$$TFR_{ij} = TF_{cow} \cdot r_{cow} \tag{14}$$

It is written as the NEL requirements per dairy cow (TF_{cow}) times the cow-ratio (r_{cow}) (see equation 15).

The NEL requirements per dairy cow are calculated following the guidelines by the Dutch Ministry of EZ (see also Tamminga et al., 2004). The energy requirements of calves and heifers is not taken into account in this model.

$$TF_{cow} = 1.02 \cdot (\overline{NEL}_{milkprod} + \overline{NEL}_{maintenance} + \overline{NEL}_{premium}) = 6374.8 kJNEL / cow / year \tag{15}$$

$$\overline{NEL}_{milkprod} = 3747.56 kJ / cow / year$$
$$\overline{NEL}_{maintenance} = 1900.24 kJ / cow / year$$
$$\overline{NEL}_{premium} = 602 kJ / cow / year$$

Given the NEL requirements and the feed production for grassland, the amount of feed bought can be calculated as denoted in equation (16).

Feed costs

It is assumed that the costs for buying feed are higher than for selling feed. We assume a 10% variation around the feed price of 0.19 euro/NEL. The feedshortage/surplus on parcel level (TFB_{ij}) is calculated using the following equation:

$$TFB_{ij} = TFR_{ij} - DMNEL_{ij} \qquad (16)$$

The total feed bought can be calculated as the total feed required by the dairy cattle (TFR_{ij}) minus the yield of energy production value from grass ($DMNEL_{ij}$).

Manure disposal costs

Whenever the nitrogen production (NP_{ij}) from dairy cows grazing on the parcel exceeds the legal limits of 250 kg N/ha the farmer needs to dispose of the manure from the parcel. Costs are involved to do so. Average cost of manure disposal (MAR_{ij}) is taken as 2 euro/kg N based on CBS (2009) and is calculated from the manure disposal cost or manure application revenue per m^3 manure (Middelkoop, 2007).

when $NP_{ij} > 250$ then $MAR_{ij} > 0$ (17)

The nitrogen surplus (MAR_{ij}) is a cost when the total nitrogen production (NP_{ij}) exceeds the legal limits of 250 kg N/ha. Whenever there is a shortage, the farmer is assumed to apply nitrogen on the parcel until a maximum of 250kg.

When $NP_{ij} < 250$ then $MAR_{ij} < 0$ (18)

Fertilizer costs

On grassland a fixed amount of 35 kg N fertilizer per ha is assumed to be used based on Aarts (1995, 1996, 2000). Later on, the fertilizer use will be calculated as depending on size of the parcel and number of dairy cows within a regression analysis using FADN-data. For now, we stick to the 35 kg N/ha.

$$FC_{ij} = p_{fert} \cdot 35 \cdot parcel_{grass} \qquad (19)$$

This results in fertilizer costs (FC_{ij}) which are calculated by the price of fertilizer, which is set at 0.70 euro/ kg N (p_{fert}) (CBS, 2009) times the fertilizer use, times the hectares of grassland ($parcel_{grass}$).

Transport costs

Total transport costs (TRC_i) depend on the distance from the parcel to the farmstead (km_i). For each parcel this distance is known. A fixed average of $TRC_{fixed} = 50$ euro costs per kilometer is used (based on Kellermann et al., 2007), to represent the costs of machinery, manure and cattle transport to the parcels. Furthermore, a constant ($const$) is used to represent the costs of mowing and other machinery on the parcel, multiplied by the size of the parcel. This constant is now set at 50 euro.

$$TRC_i = TRC_{fixed} \cdot km_i + const \cdot parcel_{ij} \tag{20}$$

Maizeland parcels

Maizeland is included in the model but is not taken into account for the agri-environmental schemes which a farmer could choose. It is assumed that grassland parcels cannot be switched into maizeland parcels and vice versa for reasons of simplicity. Maizeland is used for the production of fodder for the dairy cattle in the model. In the model, two types of revenue can be distinguished for the maizeland parcels: manure disposal revenue (150 kg N/ha, based on Ministry of Economic Affairs regulations) and feed revenue (14973 NEL kJ/ha, based on Middelkoop and Aarts, 1991).

Manure disposal revenue

On maizeland parcels, no nitrogen is produced as grazing is not allowed. The fixed maximum manure application for maizeland is set by the Dutch Ministry of Economic Affairs at 150 kg N/ha. Average revenue from manure application is set at 2 euro/kg N based on CBS (2009) and is calculated from the manure disposal costs per m^3 (Middelkoop, 2007). Whenever the farm agent has a negative nitrogen balance, he or she is able to attract external manure on the farm and a revenue could be gained. Transportcosts are calculated in the same way as done for grassland parcels.

Agri-environment schemes

Farmers receive a subsidy of 1018 euro ($S = 1018$) per hectare for applying agri-environment contracts on their parcels (based on legal requirements Ministry of Economic Affairs).

$$(S_i) = S \cdot parcel_{ij} \tag{21}$$

Transport costs

Transportation cost for parcels with AESs is assumed to be lower than for conventionally managed parcels. A fixed average of TRC_{fixed}^{nature}=20 euro costs per kilometer is used. This is lower than the transport costs for conventional farming, because it is assumed that less transport for i.e. manure disposal is needed. The transport costs (TRC_{ij}^{nature})depend on the distance from the parcel to the farmstead (km_i) and the constant parameter ($const$) which is also equal to 20.

$$TRC_{ij}^{nature} = TRC_{fixed}^{nature} \cdot km_i + const \quad \cdot parcel_{ij} \tag{22}$$

4. Sensitivity analysis of a spatially explicit rural agent-based simulation: Application of One-at-a-time and Monte Carlo analysis approaches

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Abstract

In this chapter sensitivity analyses are carried out for a spatially explicit rural agent-based simulation used to assess the impact of agricultural policy interventions, market dynamics and environmental change. The chapter illustrates the problems encountered when analysing the sensitivity of an agent-based simulation to changes in parameter settings. Two different agri-environmental policy scenarios are applied as well as two approaches to sensitivity assessment: one-at-a-time and Monte Carlo sensitivity analyses. In the model, farm agents are heterogeneous with respect to their economic and environmental characteristics and their economic decision making is explicitly modelled within their spatially explicit rural landscape. The simulations are built upon actual data sets: annual agricultural census, annual registration of land use per parcel, and detailed soil and groundwater maps. In this type of complex models, non-linearity occurs and sensitivity analysis must be conducted to discover for which parameter changes the models' outputs are most sensitive. Considered outputs include the farm agents' operational farm income and size of the area contracted for agri-environmental schemes. The two methodologies are compared and recommendations for sensitivity analysis of spatially explicit rural agent-based models are proposed. It is shown that a mixed approach would lead to a better understanding of the model's behavior, and would further enhance a correct description of the simulation's sensitivity response.

4.1 Introduction

Rural landscapes are subject to processes of change, and policy makers seek to steer such changes through interventions (Pedroli et al., 2007). Explaining and predicting behaviour of land managers is useful to policy makers aiming at preserving the rural landscape. The rural landscape is denoted as a social-ecological system (SES), comprised of social and economic (or human) and ecological (or biophysical) characteristics. This concept recognizes that social, economic and biophysical characteristics considered in isolation can each provide a partial understanding at best, and that all three aspects must be taken together to obtain a full understanding of the system dynamics (Berkes, 2003). This means that the underlying structures of a rural social-ecological system are complex, resulting in a complex system with structures and processes operating at different (spatial) scales in the rural SES. Evaluating the impact of agricultural policy intervention on farmers' decision making therefore is a complex process, taking into account a heterogeneous population, situated in a heterogeneous landscape, with corresponding non-linear behaviour. Schouten et al. (2012b, 2013a) explore the impact of agricultural policy interventions on farmers' investment decisions and the surrounding landscape using a spatially explicit agent-based model. The model focuses on farm agents' decisions to acquire more land or divest themselves of it. To show the impact of such decisions on the landscape, they are made spatially explicit by mapping agricultural parcels and examining which parcels will be transferred by whom to whom. Actual data sets are used to model the farm agents and their respective parcels, which results in heterogeneity in farm's characteristics and parcels' size, quality, shape and distance to the homestead. The data sets are drawn from annual agricultural census files, registries of land use per parcel, and detailed soil and groundwater maps.

A fundamental goal of complex systems analyses is to gain insight into the diverse interactions operating in a system that produce particular dependent outcomes. However, the greater the complexity of the system, the more difficult it is to identify the key interactions or crucial tipping points in a system (Messina et al., 2008). In many cases, data are inadequate to specify all elements and interactions of a system, and therefore the model developer must build assumptions into the representation of the system. This is particularly true for models of systems with complex human-environment interactions, such as rural SESs, where data span a broad array of social and biophysical domains. Given the rapidity of growth in ABMs for human-environment interactions, and the absence of pre-existing work or standards, many modellers either minimize model evaluation or use standard statistical methods that do not account for complexity (Verburg and Veldkamp, 2005). However, complexity science contends that many systems are best understood as being characterized by phenomena such as emergence and path dependence. Especially ABMs are known to be very sensitive to parameter changes in some ranges of the parameter space. Small changes in parameter values may have dramatic consequences for the state of the system, while changes in other parts of the parameter space have little effect (Burgers et al., 2010). This property of ABMs is usually referred to as non-linearity. It is not just a property of ABMs, it is a general property of complex systems. In general, it is considered good modelling practice to perform sensitivity analysis as part of model verification (Saltelli et al., 2000; Richiardi et al., 2006). Saltelli et al. (2000) define sensitivity analysis as the study of the relationships between information flowing in and out of the model. More precisely one could say that sensitivity analysis studies the effects of variations of parameters and inputs on model outputs. Burgers et al. (2010) urge two reasons to perform extensive sensitivity analysis on agent-based models: great uncertainty about actual values of model parameters, and non-linearity. Before a conclusion can be drawn on the basis of an agent-based model, the modeller must search for the regions in parameter space where stable, maybe inactive, states of the system occur and where the model is insensitive to parameter changes, regions where tipping points occur and system behaviour changes dramatically in case of small parameter changes, and regions where the system is more or less proportionally sensitive to parameter changes.

This chapter presents the application of two methods of sensitivity analysis on the spatially explicit rural agent-based model by Schouten et al. (2012b, 2013a). Both one-at-a-time and Monte Carlo sensitivity analyses are carried out. One-at-a-time sensitivity analysis consists in varying selected parameters one after the other, while all other parameters are being kept constant at their nominal value (also referred to as ceteris paribus approach) (Saltelli et al., 2000). Monte Carlo sensitivity analysis involves the variation of values for all selected input parameters simultaneously using Monte Carlo sampling from pre-defined probability distribution functions (Hamby, 1994; Saltelli et al., 2000). Following Jansen et al. (1994) and Burgers et al. (2010) two principles are applied:

1. Meta-modelling of results of parameter sets drawn at random from the joint distribution
2. Analysis of contributions of Top Marginal Variance (TMV) and Bottom Marginal Variance (BMV) of individual parameters to the variance explained by the meta-model.

Section 4.2 introduces the model and the parameters taken into account. Section 4.3 presents the two approaches of sensitivity analysis. Section 4.4 presents the results of the two approaches. Section 4.5 concludes the chapter with an evaluation of the applied methods.

4.2 Modelling spatially explicit rural agents and their surrounding landscape

The core of the model analysed in this chapter is the understanding of an agent-based system for the purpose of agricultural policy assessment while simulating the agents and their corresponding landscape in a spatially explicit way. The model establishes a virtual world of a rural region and comprises a large number of individual farms that operate in the region and interact with each other and parts of their environment. The model implements an abstract region, that can be initialized with empirical data on individual farms and agricultural and natural spatial structures.

Figure 4.1 provides an overview of the dynamics of the model, and the course of events during one simulation period. The model consists of an *initialization module* in which data is conditioned to be used in the model, a *farm module* that allows the calculations of farm income contribution, a *land lease market module* that facilitates the trading of land parcels among the farmers, and an *output module*. The *initialization module* contains exogenous agricultural census data (reference year 2008) and land use data from a registry on the level of individual parcels. The attributes on farm level are the farm structure, namely farmers' age, presence of a successor, type of farm, size and the total number of owned and rented parcels. At parcel level, attributes are location, shape, soil quality, crop suitability, land use, and reference to the farm using the land. At landscape level, attributes are number of farms in the region, spatial land characteristics, size and distance from the parcels to the homestead. The *farm module* keeps track of the farm management decisions, thereby taking into account attributes such as age, location, farm size, whole-farm feed and nutrient balances and farm business succession.

Each farm agent is equipped with a behavioural model that determines for each parcel whether conventional farming or an agri-environment scheme (AES) is chosen or the parcel is offered on the land market. According to their behavioural models the individual farm agents evolve subject to their current state of attributes and to changes in their environment.

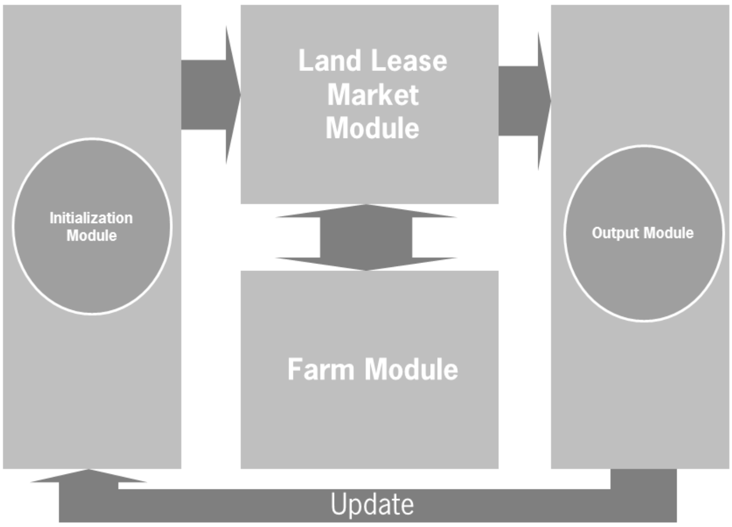

Figure 4.1: Course of events during one simulation period

The results of the farm module are input to the *land lease market module* which takes into account multiple parcels with multiple characteristics at once. Finally, the function of the *output module* is the conditioning of the model results for the next simulation period. Results at farm level and at regional level are used to update farm attributes and regional attributes in the next period.

Two different agri-environmental policy scenarios have been simulated. AESs are an example of how governments provide incentives for farmers to preserve biodiversity through direct or indirect (e.g. tax breaks) payments (OECD, 2005). In the European Union (EU) AESs are designed, at least in part, to enhance levels of biodiversity on farmland (Whittingham, 2007). A basic principle of AESs in the EU is that the participation of individual farmers is voluntary. In the simulation, farm agents base their contract choice on farm production, economic results, intensity of land use, land quality, and spatial characteristics of the respective parcel. Furthermore, the model looks at how contracts contribute to the spatial cohesion of landscapes in terms of habitat network patterns. The importance of spatial habitat network patterns is widely accepted among ecologists (see, for instance, Opdam et al., 2003) as an important condition to develop biodiversity. These spatial habitat network patterns are integrated in the model by means of a *spatial cohesion Reilly index*, which provides information on the (potential) contribution of the parcel to conserve biodiversity, which depends on its location and the surrounding landscape configuration (Cotteleer, 2008; Reilly, 1931; Schouten et al. 2013a). Equation (1) gives the formula for the calculation of the spatial cohesion Reilly-index. The calculation of the spatial cohesion Reilly-index starts at the point where the site is located. After that, the size of the nature conservation areas (abbreviation NCA) within a certain radius (i.e. 5 km) is determined, as well as the size of the AES site. Based on the sum of all the distances of the site to the nature conservation areas located within the chosen radius, and on the size of the nature conservation areas and AES sites, the spatial cohesion Reilly-index can be calculated:

$$R_i = \sum_{j=1}^{J} \frac{A_i + C_j}{d_{ij}^2} \tag{1}$$

where R_i represent the Reilly index of parcel i, A_i the surface area of parcel i, J the number of conservation areas within range, C_j the surface area of the j^{th} nature conservation area, and d_{ij} the distances from the parcel to the centres of the conservation areas. The index captures, in one number, the size of the nature conservation areas in proximity to the AES site, and the distance from the site to the nature conservation areas (Cotteleer, 2008)(see also Appendix 5A). We calculate the spatial cohesion Reilly index for each individual parcel with AESs or the potential for an AES, R_i, hereinafter referred to as Reilly points.

For the sensitivity analyses, two policy scenarios are applied:

1. A fixed annual AES compensatory payment per hectare, independent of location and spatial configuration of the landscape. This scenario is in line with current European AES programmes. The government designates potential areas.
2. A flexible compensatory payment per hectare, based on the Reilly points for the particular contracted parcel. In this way, information is added with respect to the contribution of the parcel to the long-term persistence of populations within habitat networks in the case study region. This contract type allows for higher payments for parcels that contribute more to the habitat networks.

The decision models' parameters included in the sensitivity analysis are listed in Table 4.1 For each input parameter ranges are defined based on agricultural economic and ecological literature. Whenever there is uncertainty about the theoretical range of the model parameters, a larger range was chosen.

Table 4.1: Parameters of the spatially explicit rural agent based model: Agriculturally and ecologically accepted ranges, nominal values and value ranges considered in the sensitivity analysis

Parameter	Unit	Nominal value	Value range	
			Min	Max
Fertilizer price	€/kg N	0.7	0.5	1
Feed sell percentage	%	90	0.5	1
Manure buy price	€/kg N	1.8	1.25	2.5
Manure buy percentage	%	80	0.5	1
Fixed transport costs	€/ha	50	15.81	158.113
Transport costs coefficient	€/km	50	15.81	158.11
Fixed transport costs AES parcel	€/ha	20	6.32	63.25

Transport costs coefficient AES parcel	€/km	20	6.32	63.25
Milk production per cow	kg	7875	5000	12000
Nitrogen production per cow	kg N	115	50	150
Milk price	€/kg	0.31	0.2	0.5
Feed buy price	€/net energy	1.34	1	3
Nitrogen sell price	€/kg N	2	1	4
Fertilizer grassland	kg N	35	11.07	110.68
Feed required per cow	net energy	6374.8	4000	10000
Price expectation parameter	%	0.5	0	1
Agri-environment compensatory payment	€/ha	1018	321.92	3219.19
Contract period agri-environment scheme	Year	6	2	12
Nitrogen application maize land	kg N	150	47.43	474.34
Feed production maize land	net energy	1000	500	1500
Fertilizer maize land	kg N	62.78	40	80
Maximum number of cows per hectare	cows	3	2.5	3.5
Expectation percentage	%	0.7	0.5	1

4.3 Sensitivity analysis approach

An important step in the validation of models that contain many parameters, like the agent-based model analysed in this chapter, concerns the treatment of the parameter set. The choice of which method of sensitivity analysis to adopt is difficult, since each technique has its strengths and weaknesses. Different methods may provide different types of information about the effects of parameter changes. Analysing sources of uncertainty in model outputs and testing the model's degree of nonlinearity requires that different sorts of sensitivity analyses are performed. In this chapter we used a mixed methodological approach, wherein we simulate the uncertainties one-at-a-time (OAT) and then together in a Monte Carlo simulation using random sampling.

Not all parameters that were estimated during initial model development are included in the sensitivity analysis. Schouten et al. (2013a) present results of a one-at-a-time sensitivity analysis for the percentage of Reilly points contracted. Especially for parameters with respect to grass production (mineralization of grassland, leaching coefficient grassland) this output shows very sensitive. However, for these parameters we assume no uncertainty in the values that farmers use to take their decisions. The applied parameter values are commonly used by farmers and their advisors in The Netherlands and are widely used throughout agricultural economics literature (see Middelkoop and

Aarts, 1991; van de Ven, 1992; Groeneveld et al., 1998; Groeneveld et al., 2001, and Peerlings and Polman, 2008). Therefore these parameters are left out of the analyses conducted for this chapter.

4.3.1 One-at-a-time analysis approach

A standard one-at-a-time sensitivity analysis approach following Campolongo et al. (2000) is applied in the present chapter to assess the impact of parameters on the following simulated outputs.

- Mean gross margin of farms in the region
- Mean farm area (in hectares) in the region
- Total contracted AES area (in hectares) in the region
- Total Reilly points of contracted parcels with agri-environment schemes

These outputs are relevant for agri-environmental policy evaluation, focusing on business-economic and ecological developments at regional level. Sensitivity of these outputs to parameter variation is calculated for each parameter one-by-one. For that purpose a simulation is run for 25 years, with all parameters set at the nominal value, except one which is set at either the maximal or the minimal value according to Table 4.1. This procedure is repeated for each parameter, once with the maximal value and once with the minimal value. The analysis of the results takes averaged values of the outputs over the 25-year simulation period.

This form of sensitivity analysis is selected because it is easy to understand by non-experts, relatively simple to implement and because it provides a direct assessment of sensitivity without using any transformation in the relationship between model input and model output. Hamby (1994) mentions the following disadvantages of the one-at-a-time approach i) it is more computationally intensive than other methods when the analysis involves a large number of parameters, ii) it is not suited to study the influence of large variations of input parameters on model predictions, and iii) it does not take into account interactions resulting from the simultaneous variation of multiple parameters.

Because of the disadvantages ii) and iii) mentioned above, we also apply a Monte Carlo approach.

4.3.2 Monte Carlo random sampling

A Monte Carlo approach was chosen because it allows for simultaneous variation of the values of all input parameters, in contrast to the simpler one-at-a-time sensitivity analysis. In this approach, we deal with a regression-based sensitivity analysis: a meta model in terms of the input parameters is fitted to an output variable. The output is produced by simulation runs using input parameter sets generated by Monte Carlo (random) sampling. The relative importance of individual input parameters on output variables is assessed by decomposition of the variance of the output variable. A first inspection of scatter plots of outputs against parameters can indicate the most important parameters to focus on, but the key issue in this approach is meta-modelling to find a regression model that can serve as a basis for decomposition of variance. The calculation is successful if the percentage of variance accounted for by all inputs considered is close to 100, since the analysis only accounts for that part of the variance of the output that is explained by regression (Goedhart and Thissen, 2009). Jansen et al. (1994) define the top marginal variance (TMV) of an input as the variance reduction that would occur if the input would become fully known. The bottom marginal variance (BMV) is the variance that the meta model cannot explain without the input parameter. When there are no correlations between parameters TMV and BMV of a parameter are equal if and only if that variable is not interacting or interchangeable with any other variable. Comparison of TMV and BMV can be used to check for interchangeability unless interaction-terms are important. If interaction terms are taken into account in the regression model, the BMV is defined as the variance that cannot be explained without the input parameter and all interaction terms including this parameter.

Analysis of combined input uncertainties such as the Monte Carlo variance is thought to be a more appropriate method of sensitivity analysis than OAT for complex models such as the analyzed in this chapter. This is, because a large scale global analysis can incorporate system interactions among inputs or driving functions in the model, leading to dependences and nonlinear system response, while an OAT analysis cannot. However, such nonlinear system responses can complicate interpretation of results. Therefore, Dennis et al. (2000) denote that both approaches are complementary. In models where dependences and nonlinearity are small, directed series of OAT sensitivity simulations can show the sources of change in the system, and results can be interpreted in the light of results from the global simulation. Applying them in a mixed approach would lead to a better understanding of the model’s behavior, and would further enhance a correct description of the models’ sensitivity response.

4.4 Results

4.4.1 One-at-a-time sensitivity analysis results

Figure 4.2 presents results of the OAT analyses for the four outputs in the first policy scenario with designated areas and fixed compensatory payment per hectare.

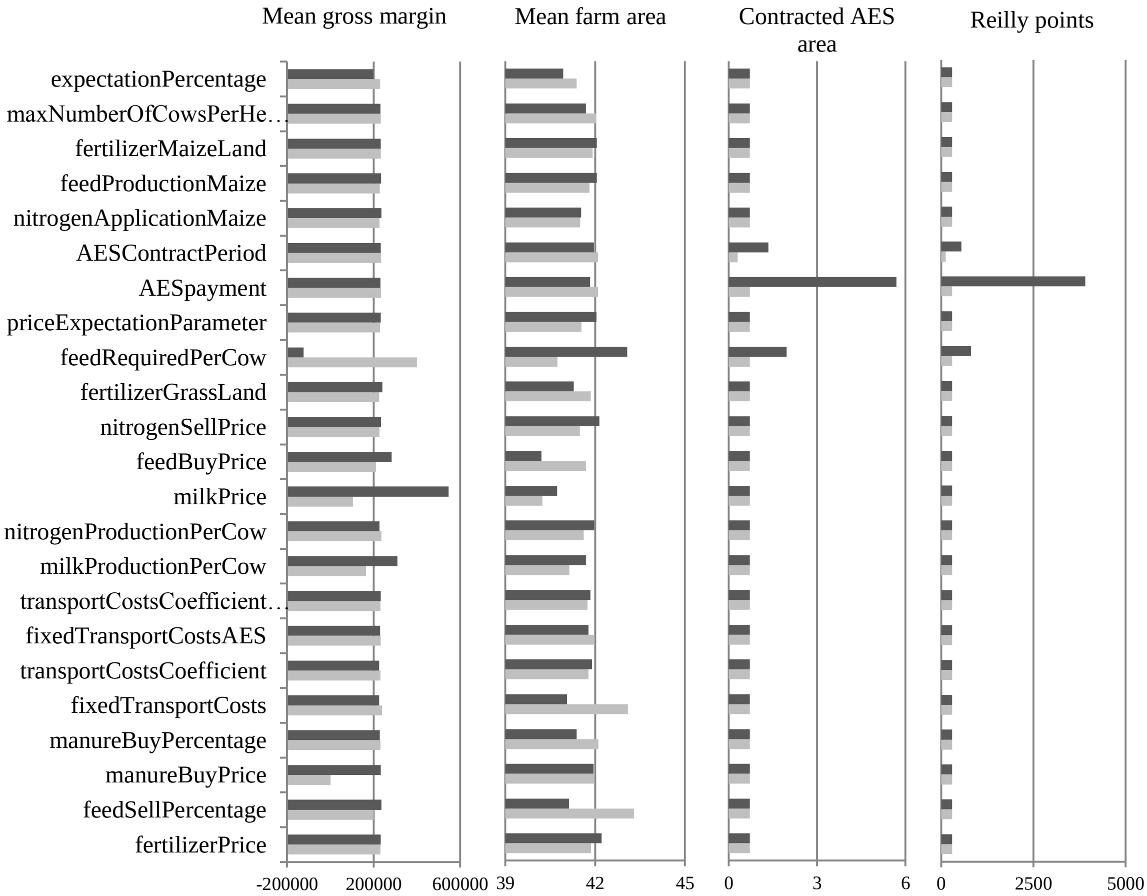

Figure 4.2: Sensitivity of four outputs to 23 parameters in the fixed payments policy scenario, according to the OAT analysis; the dark grey, upper, bars depict the values of the outputs for the maximal value for each parameter; the light grey, lower, bars depict the values of the outputs for the minimal value for each parameter, while all other parameters are set at their normative values

Figure 4.2 shows that the different outputs of the simulation are sensitive to different parameters:

- The output mean gross margin is mostly affected by variations in feedRequiredPerCow, milkPrice, manureBuyPrice, and milkProductionPerCow.
- The output total area seems to be sensitive to parameters related to transport costs, feed requirements for dairy cows, and prices of cattle feed. However, it is interesting to see that for some parameters, for instance milkPrice, the values of the output at the extreme values of the parameter deviate from the average value, which indicates a nonlinear sensitivity of the output for this parameter.
- The parameters AESpayment (the annual payment per ha), AESContractPeriod, and feedRequiredPerCow affect the contracted area and the associated Reilly points. Parameter AESpayment does so most dominantly.

Figure 4.3 presents results of the OAT analyses for the four outputs in the second policy scenario with allocation and compensation of agro-environmental schemes according to Reilly points.

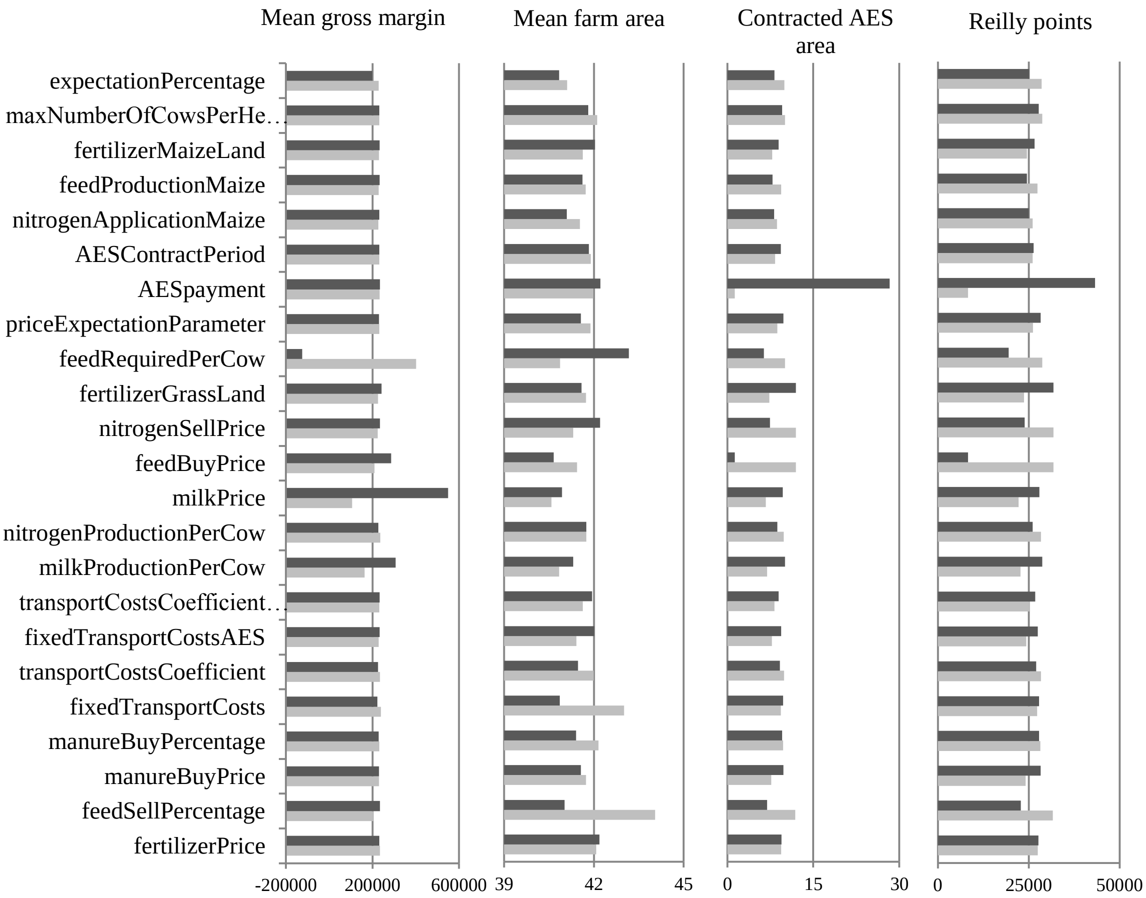

Figure 4.3: Sensitivity of four outputs to 23 parameters in the Reilly-points based policy scenario, according to the OAT analysis; the dark grey, upper, bars depict the values of the outputs for the maximal value for each parameter; the light grey, lower, bars depict the values of the outputs for the minimal value for each parameter, while all other parameters are set at their normative values

There are differences in sensitivity with the first scenario, indicating interactions of the parameters with the scenario selection:

- The mean gross margin shows to be sensitive to parameters as in policy scenario 1, namely milk price, milk production and feed requirements for dairy cows, but not for manureBuyPrice.
- The mean farm area also shows to be sensitive to the same parameters as in policy scenario 1; namely transport costs, feed requirements for dairy cows and prices of cattle feed, and again the results indicate nonlinearities.
- Contracted area and Reilly points show to be sensitive to the size of the compensatory payment as in the first scenario, but this simulation is sensitive to feed price and not to feedRequiredPerCow.

The final section of this chapter further discusses results of the OAT analyses and compares them with results from the Monte Carlo analyses presented in the next subsection

4.4.2 Monte Carlo sensitivity analysis results

Policy scenario 1: Designated areas for agri-environment schemes and fixed compensatory payment

Mean gross margin

We start with the analysis of gross margin, which is the sum of the contributions of individual parcels to the farm's gross margin. Straightforward sensitivity analysis with USAGE 2.0 (Goedhart and Thissen 2009), based on a linear meta-model results in 86.8% of the variance accounted for. Table 4.2 presents the relevant top and bottom marginal variances.

Table 4.2: Top Marginal Variances and Bottom Marginal Variances of parameters as percentage of the total variance of mean gross margin

Parameter	TMV(%)	BMV(%)
Feed sell percentage	1.7	0.7
Milk production per cow	4.4	3.8
Milk price	4.8	5.3
Feed required per cow	76.1	76.6

Variance in the mean gross margin is for 76.6% due to variation in the feed requirements per cow. This means that without good information about the feed required per cow, 76.6% of the variation in the mean gross margin will remain, so it is of utmost importance to have an accurate estimate of this parameter. Figure 4.4 shows the scatter plot of mean gross margin against the randomly drawn parameter feed required per cow.

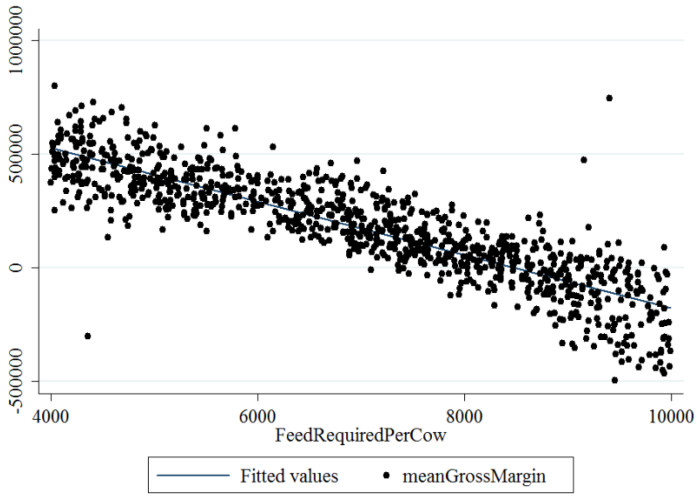

Figure 4.4: Scatterplot and linear regression of mean simulated response of mean gross margin versus parameter feed required per cow (t = -56.47; $p < 0.001$; coefficient=-117.8; R^2=0.762)

Total farm size (in hectares)

We continue with the analysis of the total farm size, in hectares, which is equal to the sum of the parcels used by each individual farm agent. Straightforward sensitivity analysis based on a linear fit results in 24.8% of the variance accounted for. Since 75.2% of the variation is not explained, several other models are tried, like polynomial models (second and third order), models taking into account second and third order interactions and conditional logit interaction terms, including smoothing splines and three degrees of freedom (36.7%). The highest variance accounted for is achieved using a smoothing splines fit with five degrees of freedom, resulting in an accounted variance of 42.3%. Figure 4.5 shows the scatterplot of mean total farm size against the randomly drawn parameter feed required per cow. This plot illustrates the influence of strong parameter interactions and non-linearity.

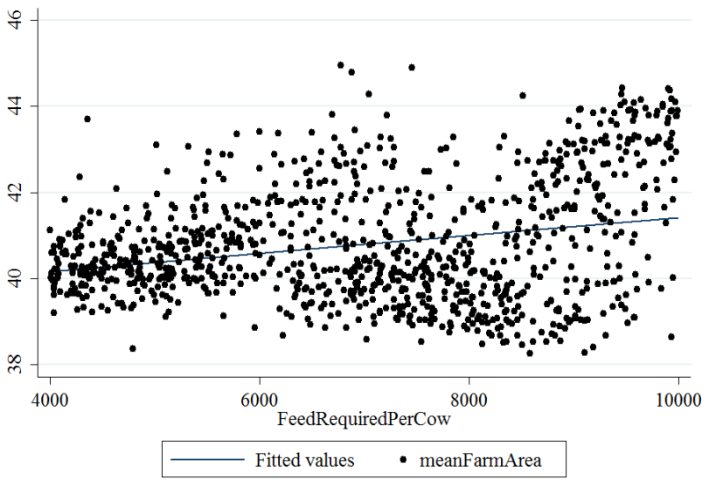

Figure 4.5: Scatterplot and linear regression of mean simulation response of mean farm area versus parameter feed required per cow (t = 8.63; $p < 0.001$; coefficient=0.00021; R^2=0.07)

Mean number of hectares contracted for agri-environment schemes

Then we continue with the analysis of the number of hectares contracted with an agri-environment scheme. A straightforward sensitivity analysis based on a linear fit results in 28.4% of the variance accounted for. The percentage of variation explained is unsatisfactory. Sensitivity for other outputs have been carried out using a polynomial model (third order) with smoothing splines (df=3), also resulting in unsatisfactory explanation of variation (36.1%). Figure 4.6 shows the scatter plot of mean number of hectares contracted for agri-environment schemes against the randomly drawn parameter compensatory payment for agri-environment schemes. It can be seen from Figure 4.6 that the meta-modelling is hampered by the great many cases in which very little parcels are offered for AES.

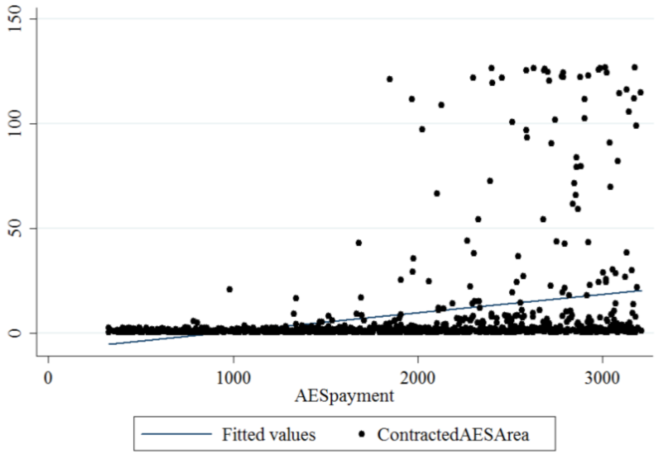

Figure 4.6: Scatterplot and linear regression of mean simulation response of contracted AES area versus parameter compensatory payment for agri-environment scheme (AESpayment) ($t = 10.55$; $p < 0.001$; coefficient=0.009; R^2=0.1).

Table 4.3 presents the Top Marginal Variances and Bottom Marginal Variances of the six most important parameters (accounting for >1% of the variation).

Table 4.3: Top Marginal Variances and Bottom Marginal variance of parameters as percentage of the total variance of the mean number of hectares contracted for agri-environment schemes

Parameter	TMV(%)	BMV(%)
Feed sell percentage	2.7	2.4
Feed buy price	13.0	15.6
Nitrogen sell price	1.0	1.2
Fertilizer grassland	2.1	3.0
Feed required per cow	0.7	2.3
Compensatory payment for agri-environment scheme	12.1	12.8

When using log transformations with a smoothing spline (df=3), a higher variance accounted for is realized (57.9%). The highest variance accounted for is realized when selecting the 6 parameters in Table 4.3. Taking into account their interactions to all degrees, results in an explained variance of 67.4%. Without interactions, they account for only 28.1% of variance. We conclude that the parameters in Table 4.3 are the most significant parameters for this output and that they have complex, non-linear, and conditional interactions. The importance of interactions is illustrated by difference between Figure 4.2 and the Monte Carlo analysis. Figure 4.2 shows no sensitivity of Reilly points for feedBuyPrice when other parameters are at their nominal values, but according to the Monte Carlo analysis the parameter must have its effects in other regions of parameter space.

Total Reilly points on contracted parcels with agri-environment schemes

Finally, we analyse the number of Reilly points on the parcels contracted for agri-environment schemes. The scatterplots present sensitivities similar to that of contracted AES area. This similarity is to be expected, since neither the area contracted nor the Reilly points associated with it are subject to evaluation of Reilly points under the present policy scenario. The statistical analysis also produces results similar to those for contracted AES area. Figure 4.7 shows the scatter plot of mean conducted Reilly points on contracted parcels with agri-environment schemes against parameter feed buy price. It indicates a similar complex, conditional, sensitivity as Figure 4.6.

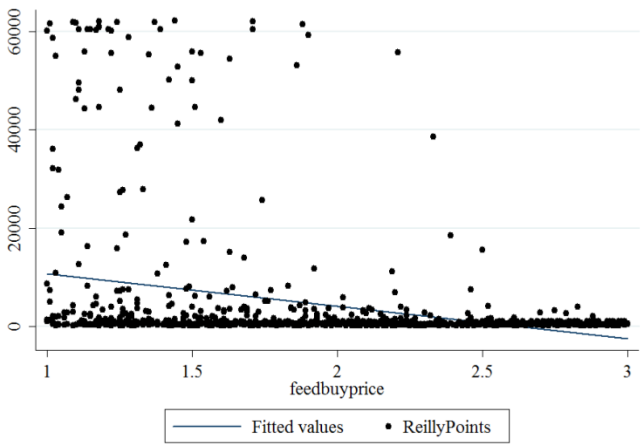

Figure 4.7: Scatterplot and linear regression of mean simulated response of Reilly points versus parameter feed buy price ($t = -10.54$; $p < 0.001$; coefficient=-6608.59; R^2=0.1).

Policy scenario 2: Allocating and compensating agri-environment schemes to farm agents based on Reilly points

Mean gross margin

Again we start with analysis of mean gross margin. Straightforward sensitivity analysis based on a linear fit with one degree of freedom results in 90.4% of the variance accounted for. Table 4.4 presents top and bottom marginal variances. The results are similar to those for scenario 1.

Table 4.4: Top Marginal Variances and Bottom Marginal variance of parameters as percentage of the total variance of the mean gross margin given policy scenario 2

Parameter	TMV(%)	BMV(%)
Feed sell percentage	1.8	0.7
Milk production per cow	4.4	3.8
Milk price	5.0	5.5
Feed required per cow	79.6	79.9
Expectation percentage	0.7	0.2

Figure 4.8 shows the scatterplot of mean gross margin against the randomly drawn milk price. The relation between gross margin and milk price is significant, but the results are widely scattered because of the great variation in other parameters, in particular feed required per cow which has a dominant effect on the outcomes.

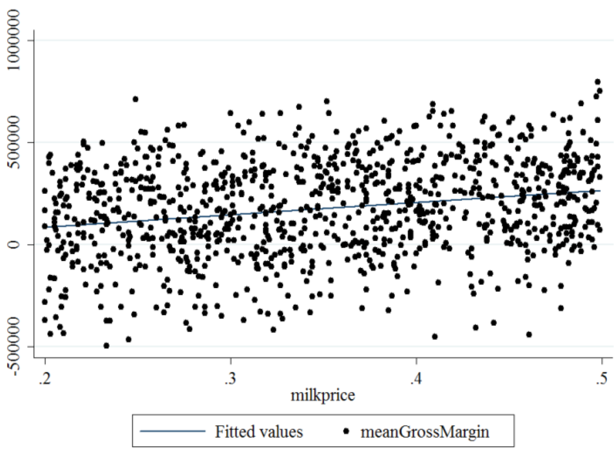

Figure 4.8: Scatterplot and linear regression of mean simulated response of mean gross margin versus parameter milk price (t = 7.3; p < 0.001; coefficient=601220.9; R^2=0.051)

Mean farm size

The outcomes for mean farm area in scenario 2 are similar to those in scenario 1. Straightforward sensitivity analysis based on a linear fit results in an unsatisfactory percentage of variance accounted for (25.3%). The highest accounted-for variance is achieved using a smoothing splines fit with five degrees of freedom, resulting in an accounted variance of 43.5%. Table 4.5 presents TMV and BMV for the relevant parameters. The most dominant one is feedRequiredPerCow. Figure 4.9 illustrates its non-linear effect.

Table 4.5: Top Marginal Variances and Bottom Marginal variance of parameters as percentage of the total variance of the total farm size given policy scenario 2

Parameter	TMV(%)	BMV(%)
Feed sell percentage	2.2	2.5
Manure buy percentage	0.1	0.9
Fixed transport costs	6.5	7.5
Milk production per cow	0.8	0.6
Nitrogen production per cow	3.7	4.9
Feed buy price	1.9	1.7
Feed required per cow	22.1	22.3
Feed production maize	0.1	0.5
Fertilizer Maizeland	0.2	0.0

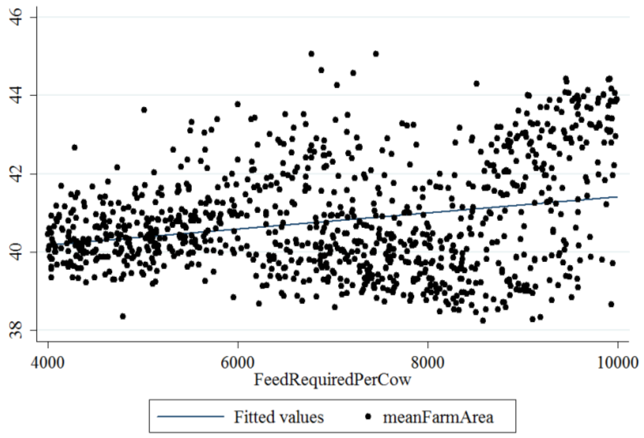

Figure 4.9: Scatterplot and linear regression of mean simulation response of mean farm area versus parameter feed required per cow ($t = 8.46$; $p < 0.001$; coefficient=0.00021; R^2=0.067)

Mean number of hectares contracted for agri-environment schemes and Reilly points

When applying a straightforward sensitivity analysis based on a linear fit to the outputs mean number of hectares contracted for agri-environment schemes and contracted Reilly points on parcels with agri-environment schemes it results in an accounted variance of respectively 82.4% and 89.3%. We conclude that the percentage of variation explained is satisfactory. Tables 4.6 and 4.7 presents the top and bottom marginal variances for both outputs.

Table 4.6: Mean contracted AES area in scenario 2: Top Marginal Variances and Bottom Marginal variance of parameters as percentage of the total variance

Parameter	TMV(%)	BMV(%)
Feed sell percentage	4.4	3.8
Fixed transport costs	0.8	0.3
Feed buy price	19.3	23.0
Nitrogen sell price	0.9	1.3
Fertilizer grassland	2.8	3.7
Feed required per cow	2.6	5.2
Compensatory payment agri-environment scheme	45.6	48.6

Table 4.7: Reilly points in scenario 2: Top Marginal Variances and Bottom Marginal variance of parameters as percentage of the total variance

Parameter	TMV(%)	BMV(%)
Feed sell percentage	2.5	2.2
Fixed transport costs	0.3	0.1
Feed buy price	15.7	19.8
Fertilizer grassland	1.5	2.5
Feed required per cow	6.2	9.8
Compensatory payment agri-environment scheme	55.3	59.0
Expectation percentage	0.3	0.0

Figure 4.10 shows a clear, nonlinear, relation between feed buy price, and the number of hectares contracted for agri-environment schemes. Whenever the feed buy price increases, the number of contracted hectares for agri-environment schemes decreases. In practice, this phenomena is also observed. Whenever prices for cattle feed increase, farmers switch parcels with agri-environmental contracts to conventional farming (i.e. production of grass) more easily.

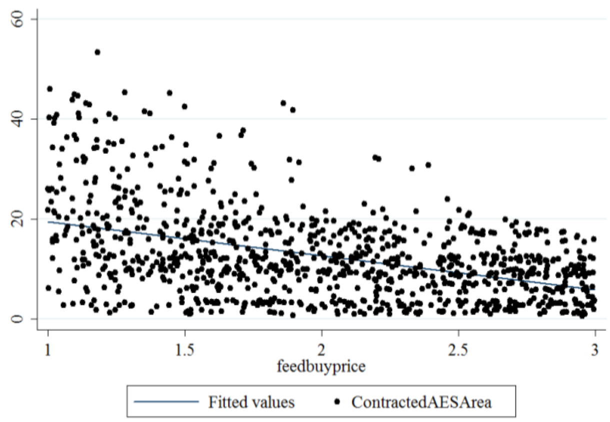

Figure 4.10: Scatterplot and linear regression of mean simulated response of mean contracted AES area versus parameter feed buy price (t = -15.5; $p < 0.001$; coefficient=-6.783; R^2=0.194)

Figure 4.11 shows the scatterplot of mean contracted Reilly points against the randomly drawn parameter compensatory payment for agri-environment schemes. The relation is clear. Budget constraints limit the total number of Reilly points to be contracted.

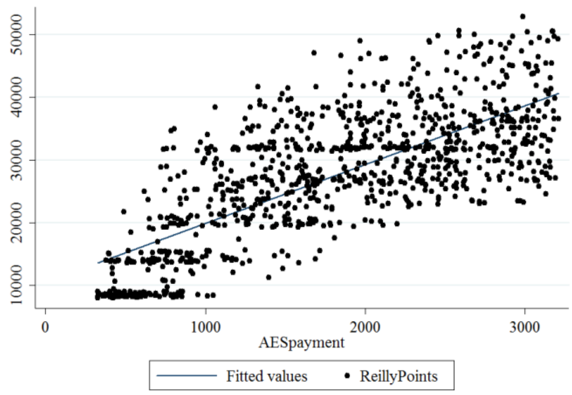

Figure 4.11: Scatterplot and linear regression of mean simulation response of Reilly points versus parameter compensatory payment for agri-environment schemes (AESpayment) (t = 35.14; $p < 0.001$; coefficient=9.384; R^2=0.553)

4.5 Discussion and conclusions

Comprehensive sensitivity analyses were carried out for a spatially explicit rural agent-based simulation, following two different methods: i) a one-at-a-time approach where each parameter was varied one after the other, while all other parameters were kept at their nominal values; and ii) a procedure based on Monte Carlo sampling where random sets of input parameter values are related to outputs of the simulation. For the sensitivity analyses, two policy scenarios are applied: A fixed annual AES compensatory payment per hectare, independent of location and spatial configuration of the landscape (Scenario 1) and a flexible compensatory payment per hectare, based on the Reilly points for the particular contracted parcel (Scenario 2).

The one-at-a-time approach conducted on both policy scenarios provides a rapid insight into the importance of parameters. The sensitivity for the outputs gross margins and mean farm area is similar across scenarios. These outputs are sensitive to changes in the parameters feed required per cow, milk price, manure buy price, milk production per cow, fixed transport costs, and feed sell percentage in both scenarios. Furthermore, the results indicate strong interactions and nonlinearities for the output mean farm area. Sensitivity for the outputs contracted AES area and number of contracted Reilly points is different across scenarios. These outputs are sensitive to parameters defining the agri-environment schemes in both scenarios. In addition, they are sensitive to feed required per cow in Scenario 1 and to feed buy price in Scenario 2.

It is remarkable that the contracted AES area and Reilly points do not show sensitivity to milk price in the analyses presented in this chapter, while according to Schouten, et al. (2013a) milk price has its effects. However, this sensitivity only occurs at milk price levels above approximately 1 euro per kilogram, which is deemed unrealistic according to experts. This phenomenon can be explained as follows. Budgets for AES contracts are limited. Farmers offer their least productive parcels for AES. The break-even point where it would pay off to use these parcels for feed production lies far beyond the limits set by AES budget and realistic milk price expectations. Within the limits the only thing that matters is the soil quality.

The Monte Carlo approach confirms the one-at-a-time simulation results and gives a further insight into the nature of the relations between the parameters and outputs. Outputs are non-linear in many cases as is shown by the scatterplots. Furthermore, the use of meta-modelling and Bottom and Top Marginal Variances gives insight into the interactions between the parameters. Parameters showed to inhabit conditional terms. However, in the cases where the parameters had strong and complex interactions (e.g., figures 4.6 and 4.7) the meta-modelling could be used to identify the relevant parameters, but it was not helpful in exploring the regions in parameter space where exceptional effects can occur.

According to both analyses, feed required per cow is the parameter which mostly affects the outputs. This implies that it is important to use a good estimate for this parameter to ensure reliable results. Fortunately, there is a significant amount of literature available on this topic in which the relations to breed of cattle, lactation period, stable type, and grazing method are extensively discussed (Tamminga et al., 2004). We made assumptions about these determinants in relation to the present case study.

In this study the sensitivity is analysed for a particular population within a specific spatial-explicit landscape. These specific characteristics of landscape and population will probably affect the results to a large extent. Whenever the model is applied to another region, a new sensitivity analysis should be conducted.

Applying a combined approach to sensitivity analysis of an agent-based simulation has proved a useful exercise. The one-at-a-time approach gave a clear and comparable overview of the results found for different outputs under different scenarios. The Monte Carlo approach gives a deeper insight into the sensitivity of outputs for parameters, and through meta-modelling insight is given into the nonlinearities and interactions between parameters. Therefore the Monte Carlo approach is a suitable method to investigate sensitivity of agent-based simulations. Non-linearity is a general characteristic of agent-based simulations and their complexity entails interactions. In interdisciplinary research as presented in this chapter agent-based simulation enables the integration of knowledge from various disciplines on a local level. This leads to complex interactions between parameters, for which a combination of sensitivity analysis methods as applied in this chapter enhances the insight in the simulation's behavioural properties. However, additional methods would be required for exploring the regions in parameter space where exceptional behaviour occurs due to conditional parameter interactions.

5. Resilience-based governance in rural landscapes: Experiments with agri-environment schemes using a spatially explicit agent-based model

Schouten, M., Opdam, P., Polman, N., Westerhof, E., 2013. Resilience-based governance in rural landscapes: Experiments with agri-environment schemes using a spatially explicit agent-based model. Land Use Policy 30, 934-943.

Abstract

In this chapter we apply an agent-based modelling approach to improve our understanding of how government payments to enhance public values in social-ecological systems can contribute to the resilience of the system. As a system we take a rural area with high quality nature including farmers managing this area. These farmers make the decision either to produce milk for the world market or bring their land under the agri-environment scheme (AES), which is supposed to enhance biodiversity at landscape level. We explore how farmers respond to introducing a flexible compensatory payment related to the degree to which AES parcels contribute to the spatial coherence of the local network of nature areas. We use this characteristic of the location of AES parcels as a proxy for higher species diversity. We also explore how farmers respond to increased volatility in output prices, which we consider as an example of a large scale disturbance with a potentially major implication on the spatial conditions of the network of nature areas. We find that if payments are spatially conditioned, farmers bring fewer parcels under the AES, but with a higher contribution to the spatial conditions for species diversity. We also find that if the payments are spatially restricted, the AES parcels are less sensitive to fluctuations in output prices. Assuming that it takes several years for a parcel with conventional farming to increase biodiversity, we conclude that if the government introduces a spatial condition into the AES payment system, the social-ecological system that we have considered would increase in resilience, because the condition for biodiversity would become less sensitive to large scale disturbances due to increased price fluctuation on the world market.

5.1 Introduction

In the last decades, substantial losses of biodiversity occurred in Europe, and agricultural intensification is a major driver of this change (Hanley et al., 2012). The rural landscape provides ecosystem services such as food, forage, fibre and bioenergy (‘provisioning services’). Biodiversity plays a significant role in providing these services through maintaining the natural ‘supporting’ ecosystem services that make agriculture productive, such as pollination, biological pest control and soil nutrient renewal. Intensification of agricultural production occurs through conversion of land use in rural landscapes from complex natural ecosystems to simplified managed ecosystems and an intensification of resource use, including higher inputs (i.e. artificial fertilizers) and agricultural outputs, which is typical for agro ecosystems. On local level, intensification is witnessed through intensified farming practices. At landscape level, agricultural intensification combined with enlarged fields to enhance farming efficiency results in homogeneous landscapes with little non-cultivated areas. The resulting fragmentation of natural habitat is a major cause of extinction of fragmented, small and isolated populations (Tilman et al., 2002; Tscharntke et al., 2005).

However, agricultural practices can also enhance biodiversity and farmers can help to maintain natural ‘supporting’ ecosystem services. Especially, low intensity land-use practices of agriculture greatly promote habitat diversity in the European human-dominated landscapes (Tscharntke et al., 2005). To maintain biodiversity and ecosystem functioning, effective rural governance is required, involving farmers as important land users (Kampmann et al., 2012; Moonen and Bàrberi, 2008). Within the EU Common Agricultural Policy (CAP), agri-environment schemes (AESs) are an example of how governments provide incentives for farmers to preserve biodiversity. However, the effectiveness of AESs to achieve that aim has been questioned (see Whittingham, 2011). Baylis et al. (2008) suggested both ecological and governance related reasons for this lack of effectiveness. For example, AES payments are irrespective of the ecological and spatial context of the subsidized land parcels, and their benefit to the farmer is affected by large scaled economic processes, resulting in a lack of continuity during a time span that allows biodiversity to establish.

In this chapter we address this dynamic relationship between intensity of farming and local conditions for biodiversity. We will place this relationship in the context of resilience thinking. Holling (2001) defines resilience as ‘the amount of disturbance that can be sustained before a change in system control or structure occurs’. We consider the landscape as a social-ecological system, in which socio-economic, (i.e. farming practices) and physical components (i.e. biodiversity) interact. Especially in the context of ecosystem and resource management, the interactions between these two determine the system’s ability to cope with disturbances. However, the behaviour of these complex non-linear social-ecological systems is highly unpredictable, and the effects of disturbances and policy interventions can be highly uncertain (Anderies et al., 2006b). In this chapter we consider food production and sustaining biodiversity as two ecosystem services that can be produced by farmers in rural landscapes, where food production generates income by supplying products to the world market and biodiversity production by AES payments. Our aim is to explore how farmers decisions to include the biodiversity service in their enterprise are affected by fluctuating market conditions and how they respond to instruments of AESs, that serve as a governmental incentive to foster the landscape cohesion for biodiversity. We simulate how this governmental incentive can be made effective under fluctuating market conditions. We make use of a spatially explicit agent-based modelling (ABM) approach to assess how AESs influence farmland biodiversity, while exploring the impact of disturbances imposed to the system. We thereby capture the heterogeneity between farmers as well as the spatial and institutional dynamics in land ownership and intensity of land use on the uptake of AESs.

Modelling human decisions in coupled human and natural systems by means of an ABM approach has become a popular bottom-up tool that has been extensively employed over the past decades to understand system complexity and non-linear behaviour (see, for instance, Heckbert et al., 2010; An, 2012; Rounsevell et al., 2012). Also many studies exist that focus on ABMs to investigate land use changes and consequences of land-use policies at landscape level (see, for instance, Parker et al., 2003; Bakker and van Doorn, 2009; Le et al., 2010). With respect to spatial ABMs applied to agricultural policy analysis , Balmann (1997), Berger (2001), Happe et al. (2009), Lobianco and Esposti (2010), Schreinemachers and Berger (2011) and Schouten et al. (2012b) focus on the impact assessment of agricultural policy support measures that are part of the EU CAP, taking into account both microeconomic farm management theory and modules for simulating biophysical dynamics. Advantage of these policy assessment models is that the effects of policy changes on different farm types can be shown, taking into account both structural and spatial heterogeneity of the farms in a spatial explicit way. This type of models is gaining importance as tools for managing tomorrow’s agriculture, as they allow to study a wide range of price and trade policy options. Traditionally, predicting the behaviour of individual farmers is typically based on mathematical programming methods. These models usually aggregate individual decision-making at the regional or sector level to evaluate policy options. They do not capture the interactions between actors (i.e. individual farm households) assuming that there are no transactions and information costs. Furthermore, these models do not fully capture the spatial dimension of agricultural activities and their effects on surrounding (nature) areas (Berger, 2001). ABMs focused on agricultural policy assessment are able to capture these farmers’ interactions, as well as the spatial dimension of their activities while being subject to policy interventions.

In this chapter we use the model of Schouten et al. (2012b), which builds on Happe et al. (2006) and Lobianco and Esposti (2010) by using real farm localizations, using real land coverage on spatial explicit parcels. We apply it to the case of AESs, assessing the impact of alternative governance structures while capturing the heterogeneity between farmers as well as the spatial and institutional dynamics in land ownership and intensity of land use on the uptake of AESs. As Baylis et al. (2008) and Whittingham (2011) raised the lack of effectiveness of AESs due to disregard of the ecological and governance context of which the potential conservation parcels are part, we compare the current situation with a situation that takes into account this ecological context using different governance structures. The simulation runs of the model are carried out with an empirical data set taken from a dairy region in the Netherlands. We assess how two options of AES payments influence farmland biodiversity by contributing to the spatial cohesion of habitat networks during milk price disturbances.

The structure of this chapter is as follows. In Section 5.2, the background of AESs within the European policy context is discussed and two options of AES payments are introduced that will be used throughout this chapter. In this section we also explain how we specify resilience and motivate why we have chosen the case study region. Section 5.3 introduces the general structure of the spatial explicit agent-based model and explains how we brought the two options of AES payments into the model. Section 5.4 discusses the simulation results, showing farmers' response to the two different AES options, and showing system's behaviour under milk price fluctuations. Finally, conclusions are drawn in Section 5.5 and the suitability of this approach for the systematic analysis of governance and mechanisms of resilience in rural landscapes is discussed.

5.2 Theoretical background

5.2.1 Agri-environment schemes in the European Union

Within the current CAP reforms, the process of decoupling of production support, introduced partially under the 1992 McSharry reforms, resulted in a shift of rural policy from payments to enhance short term profit-maximising towards a governance approach in which the management of rural landscapes relies less on central government direction. The current debates on 'market failure' and the significance of environmental resources have influenced the priorities of policy mechanisms. AESs were introduced in the mid-1980s to secure the delivery of ecosystem services by farmed landscapes. These schemes have, since the mid-1980s, come to play a central role in influencing the condition of the rural landscape (OECD, 2005). While introduced in Europe through the CAP, there have been similar developments in other countries, such as under the 1985 Farm Bill in the USA (Hodge, 2007). A basic principle of AESs in the EU is that farmers commit themselves voluntarily for a given period to deliver agri-environmental services on all or part of their land in return for a payment which is independent of location and spatial configuration of the landscape (Peerlings and Polman, 2008). Previous studies focused on the characteristics of farms and farmers who conclude AESs (e.g. Crabtree et al., 1998; Beedell and Rehman, 2000; Wynn et al., 2001; Vanslembrouck et al., 2002; Wenum, 2002). Van Huylenbroeck et al. (2000), Peerlings and Polman (2004) and Havlík et al. (2008) developed optimization models to evaluate the impact of AESs on farm production and economic results. The mentioned studies focused on individual farm level and the farmer's decision making. As mentioned in Section 5.1, we extend this view by focusing on how farmers can enhance biodiversity at a higher spatial scale, thereby helping to maintain the natural 'supporting' ecosystem services. This asks for a landscape approach taking into account the consequences of decisions made by farmers at the landscape level. Habitat fragmentation due to agricultural intensification leads to extinction of small and isolated species populations (Tscharntke et al., 2005). Therefore it could be beneficial for government institutions to cooperate closely with farmers while they are taking into account the ecological context of their land and land use (Kleijn et al., 2004). We provide insight into the spatial dynamics of land and land use and include an ecological perspective by focusing on the development of conditions for farmland biodiversity while assessing the impact of the current AES situation and comparing it with an alternative AES version that takes into account spatial characteristics of landscapes. In Section 5.2.2, the spatial explicit AES version is introduced.

5.2.2 Alternative AES: The importance of spatial cohesion for network populations

In many rural landscapes, the degree of fragmentation of natural ecosystems has developed to such a degree, that local areas cannot support viable populations of species that are key players in these regulating services (Saunders et al., 1991; Kinnaird et al., 2002; Myers, 2003). Opdam et al. (2003)

applied metapopulation ecology to infer spatial characteristics for configurations of landscape elements that can be used for sustainable biodiversity management. They introduced the concept of spatial cohesion of habitat networks at landscape level. The degree of cohesion of the habitat network determines whether or not local extinction and recolonization rates are in equilibrium, and whether the network allows the population to persist under stochastic demographic processes and environmental perturbation. The spatial cohesion concept implies that the number of species finding sustainable conditions in the regional landscape increases with the size and environmental quality of the network elements and the degree of connectivity in their pattern. These characteristics can be used as proxies for the number of species that potentially occurs in a landscape (Opdam et al., 2008). However, species respond differently to changes in size and connectivity: small species which have limited capacity to move across landscape are particularly sensitive to changes in connectivity and to the size of individual patches, while large species which can cross the distances between natural patches in the landscape are sensitive to the total amount of area within the landscape network, irrespective of its spatial pattern. For our purpose, we use the change of connectivity brought about by adding a piece of land to the conservation network as a proxy for the change in the spatial conditions for biodiversity in general. A further simplification of our approach is that we neglect the time required for redeveloping the piece of land from a conventional farmers grassland into a conservation grassland. This transition requires a period of at least 5-10 years. The advantages of our approach is that we obtain a measure of potential quality in the absence of long term monitoring data.

To be able to assess the potential of a specific landscape pattern to conserve biodiversity we developed a landscape cohesion method based on spatial data. For this chapter, we want to assess the specific AES-sites for their potential to conserve biodiversity thereby taking into account their spatial configuration in the surrounding landscape. A number of recent studies have highlighted the importance of the surrounding landscape on the effectiveness of AESs. Whittingham (2011) demonstrates that at landscape scale, the effect of AESs on farmland biodiversity has been shown to be positively related to nature conservation areas and land under AESs in the neighborhood. Spatial econometric literature provides an appropriate tool for this problem: The Reilly index (Cotteleer, 2008; Reilly, 1931). For this chapter, we modified the Reilly index to calculate the impact of surrounding nature conservation areas on the potential for biodiversity conservation by sites with AESs. For each parcel, the spatial cohesion Reilly index is calculated (see the Appendix 5A for method). In this way, information is provided on the (potential) contribution of the parcel to the long term persistence of network populations within habitat networks in the landscape.

An AES site located near or in a nature conservation area has a higher spatial cohesion Reilly index than a site that is located further away. Also larger sites result in a higher spatial cohesion Reilly index when compared with smaller sites. When taking the sum of the individual parcels' indexes, an indicator is given of the spatial cohesion of the landscape pattern in the whole case study area. In this way, it can be assessed which policy option contributes more to the conservation of biodiversity in the area. In section 5.3, the index is integrated into a spatially explicit agent-based model framework which is applied to a case study region in the Netherlands. This model captures both the spatial dynamics in land ownership and land use on the uptake of AESs, but also contributes to the sustainable management of biodiversity by making use of the spatial cohesion Reilly index elaborated on in this section.

5.2.3 Specifying resilience: Increased volatility in milk prices

In this section we elaborate on the way we choose to analyse resilience. For this application, we choose to impose output price disturbances, specifically milk price disturbances to the actors active within the spatially explicit rural landscape. The choice for milk price disturbances is based on the characteristics of the case study region used for this chapter in which dairy farming is a dominant form of land use. Section 5.3.1 elaborates on the chosen case study: the rural region Winterswijk in the Netherlands. Revenue from milk production is of high relevance to dairy farmers in this region, as currently they rely to a large extent on these milk prices as their main source of income. In turn, they influence the rural landscape configuration through their choices of production.

The present EU dairy market regime combines price support, through measures like intervention buying, import tariffs and export subsidies, with milk quotas to limit production levels. The 2003 Luxembourg Agreement on reform of the CAP implies that the quota system will be abandoned on 1 April 2015. Until that moment, stepwise intervention price declines, decoupling of milk premiums and gradual phasing out of the quota system are introduced. Strong price fluctuations were experienced in the period 2007-2010, with prices reaching unprecedented high levels in 2007 but falling gradually over 2008 and early 2009 causing a milk crisis in the EU and worldwide (Jongeneel et al., 2010). According to the European Commission prospects until 2020 this increased price volatility is likely to retain (EC, 2010) after the quota system is abandoned in 2015. Overall, temporarily extreme price fluctuations may lead to farm management problems, such as over- or underinvestment (because of wrong price signals and due to increased uncertainty).

Figure 5.1 gives an overview of the development of the milk price for the period 1989-2009. The figure shows how the milk crisis developed after a relatively long period of steady milk prices. The figure shows that in 2007 milk prices increased to a very high level, and sharply decreased again in the second part of 2008. In 2009 milk prices reached a level which was about 30% lower than in the peak years 2007 and first part of 2008, but was only 10% lower than in the more normal years before the strong price increase.

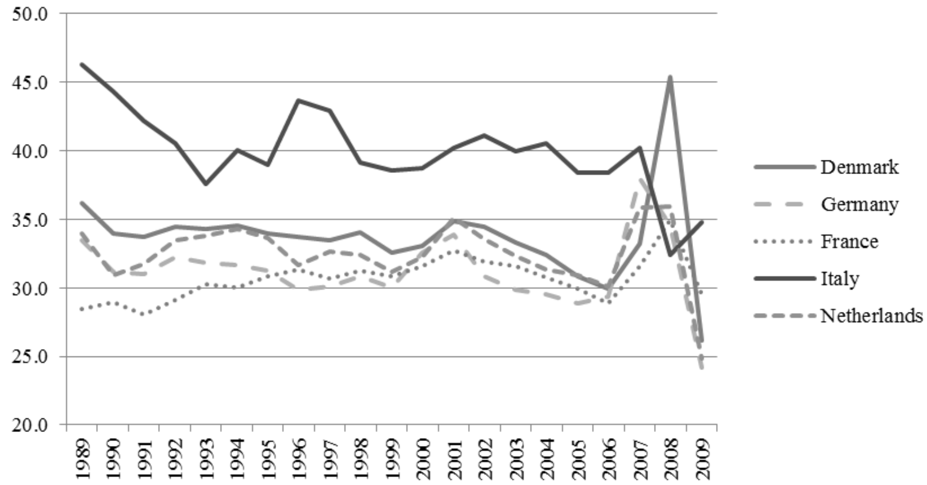

Figure 5.1: Development of the milk price received by dairy farmers in 5 European countries 1989-2009 (in eurocent/kg). Source: Jongeneel et al. (2010); FADN till 2007; 2008-2009 Dutch Dairy Board.

For the purpose of this chapter we impose milk price disturbances to the actors in the rural landscape by allowing milk prices to fluctuate over a certain period of time. This is in line with resilience literature on disturbances and disturbance regimes. White and Pickett (1985) define a disturbance as ‘any relative discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment’. A disturbance regime is defined in terms of scale, frequency, predictability and severity taking into account disturbances at different temporal scales (Turner and Dale, 1998). We will analyse how the actors in the rural landscape deal with changes in disturbance regimes. In Section 5.3.3 and Section 5.4 we discuss the imposed disturbance regimes in detail.

Analysing the resilience of the complete social-ecological system would imply that we impose disturbances of various nature and simulate the behaviour of both ecological and socio-economic indicators. For reasons of feasibility, we limit ourselves to ecological resilience, by analysing the uptake of AESs given the two options of AES payments. We assume that the larger the connectivity within the habitat network, the more species populations can survive disturbances, which subsequently results in higher ecological resilience (Hanski, 1999). In our case, the cohesion of the conservation network is augmented by adding a piece of AES land to the network as a proxy for improved spatial conditions for biodiversity (Opdam et al., 2008). This addition may increase both total area of the network and degree of connectivity. We build on a commonly accepted insight that adding land close to existing protected sites receives higher numbers of species establishing in response to improved abiotic conditions, than pieces of land at distances beyond the dispersal capacity of many species; the latter category, including many plants and small insects, plays an important role in the provision of ecosystem services.

5.3 Experimenting with options of AES payments using a spatial explicit agent-based model

5.3.1 The case study region: Rural landscape Winterswijk

For this chapter we use the agricultural region Winterswijk, which is located in the eastern part of the Netherlands, as a case study. From a landscape perspective, the area represents a highly valued cultural-historic landscape where small-scale agriculture and nature areas are closely related providing particular cultural, recreational, ecological and economic value to the region (Provincie Gelderland, 2005). The spatial structure of the landscape attributes are characterized as small fields surrounded by hedges or wooded banks (Mastboom, 1996). The size of the area is approximately 22,000 ha, in which 651 farms are present (reference year 2008). The most important agricultural sector in the region is dairy farming. Sixty percent of the main production area in the region is used for specialized dairy farming, with an average production intensity of approximately 12000 kg milk-ha-1 (Korevaar et al., 2006). AESs play an important role in the management of the area, and dairy farmers are important stewards of the rural landscape while executing AESs. Large parts of the region contain important nature conservation areas which belong to the National Ecological Network (NEN) which is part of the European Natura 2000 network. In the 1990s, the Dutch government launched the NEN as a structure of existing nature areas that was to be made more robust and cohesive by enlarging areas, improving environmental quality, and developing new areas and local ecological corridors (Opdam et al., 2008). In this way, the NEN contributes to development of biodiversity in the Netherlands (Lammers and Zadelhoff, 1996). The size of the nature conservation areas in the region is 3565 ha (289 parcels). Designated areas for AESs are located in the neighborhood of these nature conservation areas.

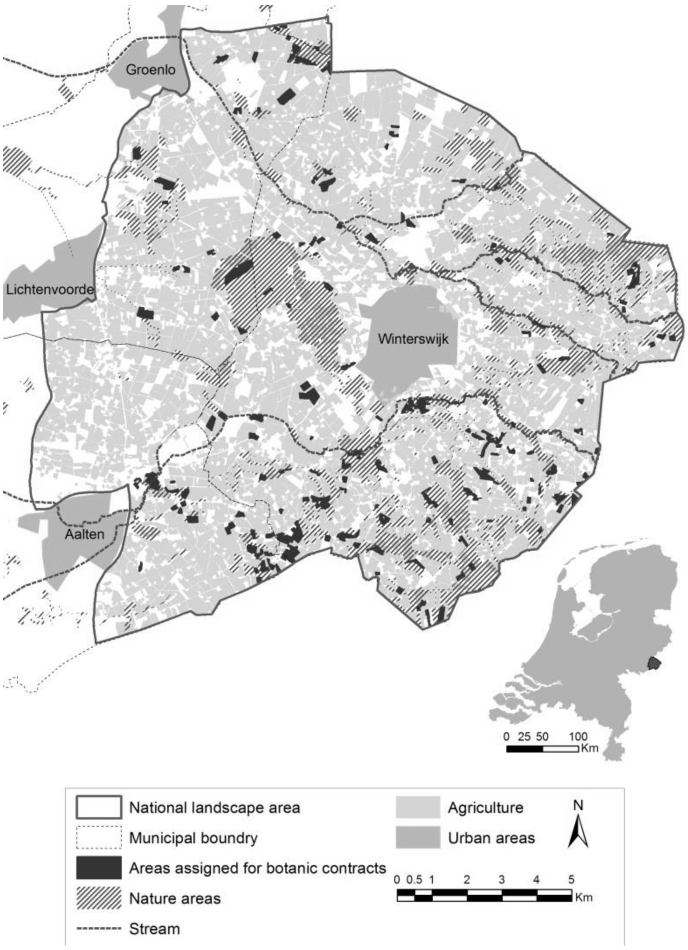

Figure 5.2: The study region Winterswijk

Figure 5.2 gives an overview of the case study region. From Figure 5.2 follows that nature areas and designated areas for AESs are mainly concentrated in the southern part of the region. Areas not included in the model are white and include small villages. The main urban area is the city Winterswijk.

5.3.2 The model

The ABM applied for this study describes the individual farmers' behaviour within the spatially differentiated configuration of the Winterswijk landscape.

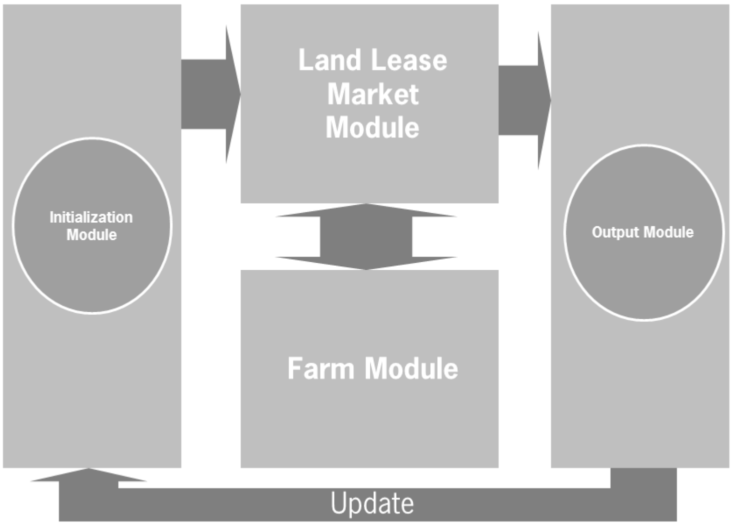

Figure 5.3: Course of events during one simulation period

Figure 5.3 summarizes the structure and dynamics of the model; extensive elaboration of the model can be found in Schouten et al. (2012b). The model consists of an *initialization module*, a *farm module*, a *land lease market module*, and an *output module*. For the *initialization module*, 206 individual farms are distinguished, each of which are taken from the Agricultural Census (reference year 2008). These farms are all specialized dairy farms, which is the main farm type in the area and together they cover 60% of the main production area in the region. Furthermore they are selected because of their importance for agri-environmental management in this area (see, for instance, Korevaar et al., 2006). Although one of the advantages of agent-based models is that they can accommodate different behavioural model types, this model distinguishes one farm agent's behavioural model, in which Agricultural Census data serves as input for the individual farm characteristics. The attributes on farm level are the farm structure, given in age of the farmer, type of farm, size and number of total owned and rented parcels. At parcel level, attributes are soil quality, crop suitability, information on ground water tables and land use which were used to integrate the production characteristics of individual parcels in the model. These characteristics are derived from Cadastral GIS-maps. At landscape level, attributes are number of farms in the region, spatial land characteristics, size and distance from the parcel to the agent's farmstead. These attributes do not change during the simulation period. In the *farm module* each farm agent is equipped with a behavioral model that guides decisions and the model keeps track of the agent's internal state described by attributes such as age, location and size. According to their behavioral models the individual farm agents evolve subject to their current state of attributes and to changes in their environment. The results of the farm module serve as input for the *land lease market module*. In this module parcels of land are reallocated by means of an auction which matches bids and asks based on creation of the largest buyer/seller surplus. Finally the function of the *output module* is the conditioning of the model results for the next simulation period. Results on farm level as well as on the regional level are used for update farm attributes and regional attributes in the next period.

Regarding AESs, we focus on AESs on grassland, with a potential uptake of 128 ha for the farms in the sample, consisting of 63 parcels. Data on this matter was distributed by the former Dutch Ministry of Agriculture, Nature Conservation and Food Quality by means of GIS-maps with potential contract area for the year 2008. Whenever there is an uptake of AESs, the farmer obliges itself for a period of six years. To assess how the two different types of AESs influence the spatial configuration as well as the resilience of the rural landscape, we added the possibility for AESs as one of the parcel characteristics, besides the parcel size, ownership and current land use. The decision whether a farm agents conducts conventional farming or an AES on a respective parcel takes place in the *farm module* (see Figure 5.3).

5.3.3 Integrating the two options of AES payments

It is assumed that the total maximum budget available for AESs in the study region amounts approximately 130,000 euros. This amount is calculated by the sum of the assigned parcels for AESs times the compensatory payment per hectare. In the current regime, the compensatory payment is a fixed amount per hectare, independent of location, parcel quality or spatial configuration in the landscape. From the perspective of landscape cohesion and the contribution to spatial cohesion of individual parcels, it is beneficial to link payments to the spatial cohesion Reilly-index. For each parcel, either conventional, with AESs or possibility for AESs, the spatial cohesion Reilly-index is calculated (see Section 5.2 and Appendix 5A for method). The total number of spatial cohesion Reilly-index points, assigned to the parcels is equal to about 62,000. We calculate the compensatory payment per individual Reilly point by dividing the total budget by the total number of assigned Reilly points. For this chapter, we define two policy scenarios on which model simulations are ran:

- *Base scenario: Fixed AES compensatory payments;*
  For the *base run scenario* we assume a fixed annual AES compensatory payment per hectare, independent of location and spatial configuration in the landscape. This scenario is in line with current European AES programmes. We run the model for different levels of fixed compensatory payment per hectare with different corresponding budget sizes. For these different budget sizes we analyze the contribution to landscape cohesion and habitat networks by showing the average number of contracted Reilly points on the contracted parcels in the simulation period.

- *Spatial differentiated scenario: flexible compensatory payments based on contracted Reilly points;*
  For this *alternative,* we assume a flexible compensatory payment per hectare, based on the contracted Reilly points for the particular parcel. In this way, information is added with respect to the contribution of the parcel to the long term persistence of populations within habitat networks in the case study region. This contract type allows higher payments for parcels that contribute more to the habitat networks. It is assumed that all farm agent can tenders for a contract, whenever this is decided on in the decision making process. The role of the government is to select those bids that will maximize the total number of Reilly points. Again, we analyze the contribution to landscape cohesion and habitat networks by showing the average number of contracted Reilly points on the contracted parcels in the simulation period under different budget sizes.

The model is simulated for 25 time periods (corresponding to 25 years, considering one generation of farmers) starting in the base year 2008. Milk price disturbances are imposed to the farm agents active in the rural landscape for a period of 5 years to mimic the period of high price peaks and falls (see Figure 5.6 for a graphical interpretation of the imposed price swings). Milk price disturbances set in after nine periods, and last until period 14 to prevent possible disorders because of warm-up time of the model in the first part of the simulation. Simulation length and warm-up time can be edited. The disturbance period of five years is chosen because farm agents in the model form expectations about milk prices based on past experience, following the theory of adaptive expectations (see Schouten et al., 2012b). Agents revise their expectations with respect to milk prices periodically which serve as input for the decision making process (following Kellermann et al., 2007). They are used in the form of a weighted moving average of the prices in the past periods. For the remaining of the simulation period, farmers experience a stable average annual milk price (calibrated on an average annual milk price; 0.31 eurocent/kg) (Jongeneel et al., 2010).

5.4 Simulation results

Table 5.1 shows the results of the two policy scenarios. In Table 5.1 we compare the average percentage of contracted AES-area, thereby taking into account the designated AES-area of 128 ha (=100%) as well as the percentage of total Reilly points contracted in the area after a simulation period of 25 years. In the current version of the model, no stochastic elements are explicitly inserted and agent behaviour and interactions are based on deterministic rules.

Table 5.1: Percentage of AES-eligible area contracted for base run with fixed AES payment and alternative with spatial differentiated payments and percentage of total Reilly points contracted for both scenarios in the current situation

Scenario	Percentage eligible AES-area contracted for current situation	Percentage Reilly points for current situation
Sc1 Base: fixed AES payment	60%	65%
Sc2 Spatial differentiated payment	25%	71%

Table 5.1 shows that the spatially differentiated scenario results in a lower contracted AES area when comparing to the base run scenario. The spatially differentiated scenario results in a higher percentage of total Reilly points contracted. Although fewer AES-area is contracted, the results show that applying a flexible compensatory payment rate based on spatial configuration and size results in higher spatial cohesion of the habitat networks, with potentially higher biodiversity.

Figure 5.4 shows the results of the model simulations for the uptake of AES-eligible area given different allocated budgets. On the *x-axis*, different sizes of allocated budget are given. On the *y-axis*, the percentage of AES-eligible area contracted is given. The current situation in the case study area is indicated by means of a red line (‘current’).

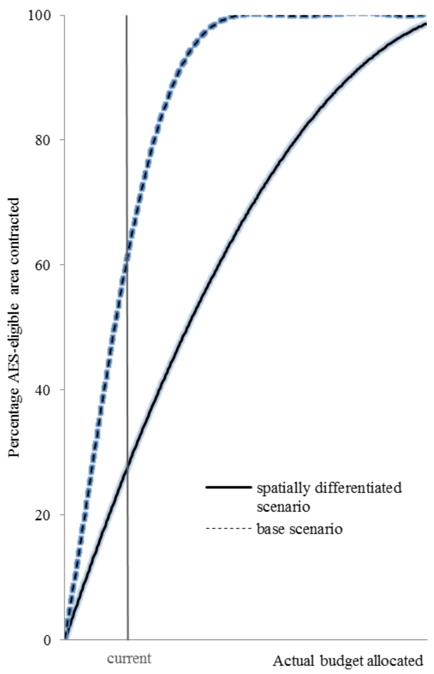

Figure 5.4: Percentage of AES-eligible area contracted for base run with fixed AES payment and alternative with spatial differentiated payments under different actual budgets allocated

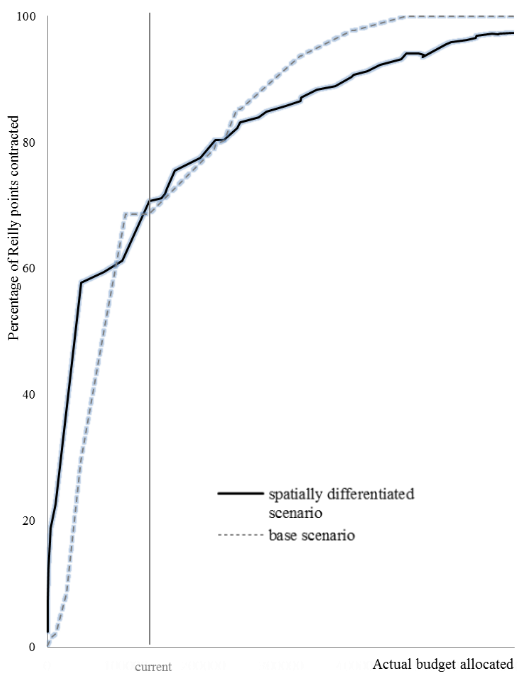

Figure 5.5: Percentage of total Reilly points contracted for base run with fixed payment and alternative with spatial differentiated payments under different actual budgets allocated

Figure 5.4 shows that for different budget sizes, the spatially differentiated scenario results in fewer contracted AES-eligible area when comparing to the base scenario. As stated in Section 5.3.3, the spatially differentiated scenario assumes a flexible compensatory payment, based on the number of contracted Reilly points. This means that higher payments are given to parcels that contribute more to the habitat networks. This higher payment for parcels with a higher contribution to the habitat network results in a lower percentage of contracted AES area, because more budget is spend on fewer contracts when comparing to the fixed payment scenario. The base scenario assumes fixed AES compensatory payments, independent of spatial configuration and therefore reaches the maximum contracted AES-eligible area with a smaller allocated budget. Therefore, Figure 5.4 shows that for the alternative scenario more allocated budget is needed to reach the same maximum contracted AES-eligible area as for the fixed payment scenario.

Figure 5.5 shows the results of the model simulations for the percentage of total Reilly points contracted, given different allocated budgets. Now, the *y-axis* shows the percentage of total Reilly points contracted. Again the current situation in the case study area is indicated with a red line (‘current’). Figure 5.5 shows that for smaller budgets, the spatially differentiated scenario results in higher percentages of total Reilly points contracted. As stated in Section 5.3.3, every farm agent tenders for a contract; the government selects those parcels with the highest contribution to the spatial cohesion of the habitat network. Figure 5.5 also shows that at a certain budget, the fixed payment scenario results in higher percentages of total Reilly points contracted. This can be explained as the point where the spatially differentiated scenario values the contribution of the remaining parcels eligible for AES to such an extent, that the number of contracted AES parcels increases at a lower pace. From an ecological perspective this can be interpreted as the parcels eligible for AESs that are relatively small and that are located further away from nature conservation areas, which results in lower contribution to the spatial cohesion of the habitat network in the landscape (low Reilly points). Because of this lower contribution, these parcels are less attractive for the government to contract.

The results indicate that whenever policy makers are targeted at achieving the highest amount of AES area, independent of spatial configuration, the current fixed compensatory payments are preferable. Whenever policy makers want to achieve the highest contribution to the spatial habitat network through their AES policy, spatially differentiated payments are more effective.

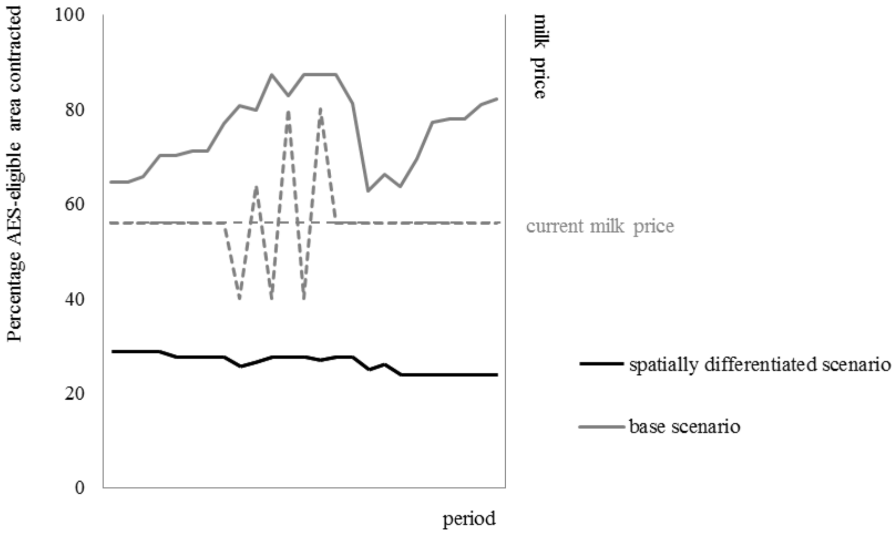

Figure 5.6: Development of percentage of AES-eligible area contracted for base run with fixed payment and alternative with spatially differentiated payments given a milk price disturbance regime during a simulation period of 25 years

Figure 5.6 illustrates that, when imposing milk price disturbances to the system, both scenarios behave in a different way. The base scenario shows to be more sensitive to fluctuations in the milk price. In low milk price years, farmers prefer to contract an AES because of the higher revenue that is gained. During high price years farmers decide for food production instead of biodiversity. Main reason for this is probably that due to the higher level of compensatory payment to parcels with a large contribution to the spatial cohesion of the habitat network, farmers are less inclined to switch to conventional food production.

Figure 5.7 shows the results of a one-way sensitivity analysis for the percentage of total Reilly points contracted when changing parameter values between a predefined range, without price shocks. This analysis shows the importance of assessing parameters' actual values, and shows how possible uncertainties about their values affects our ability to predict accurate results given the policy scenarios used in this chapter.

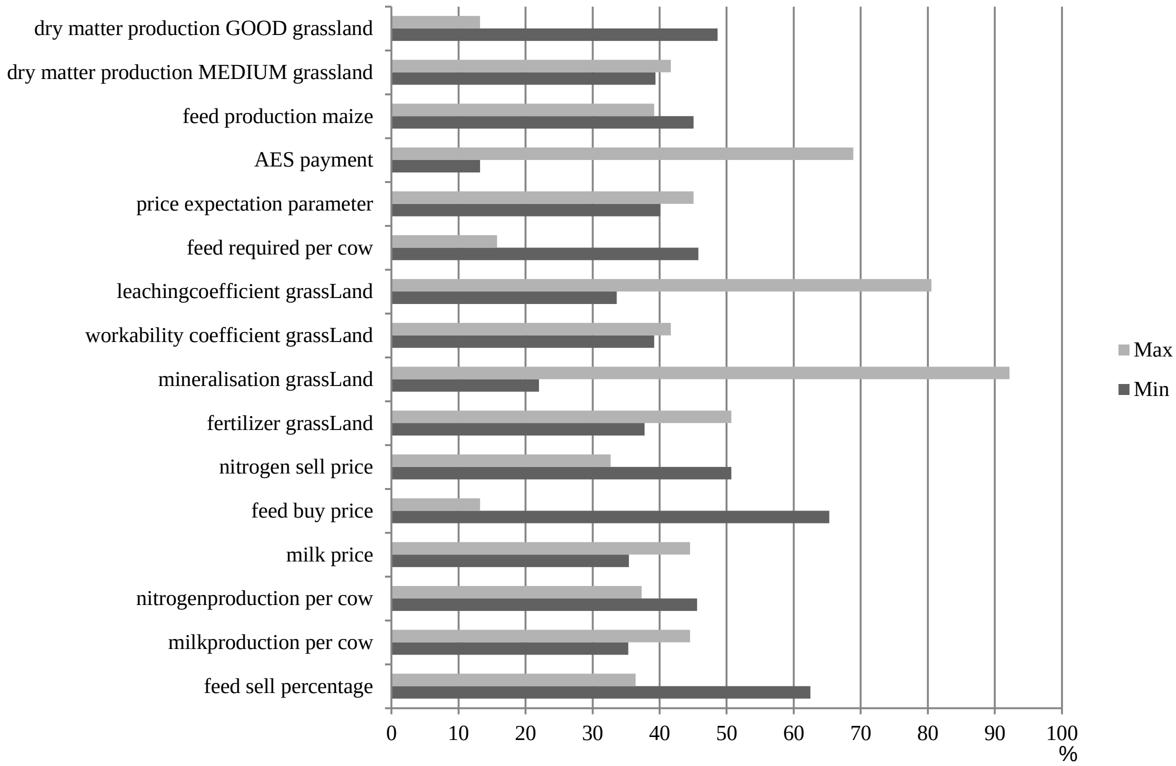

Figure 5.7: Sensitivity analysis: impact of changes in parameter values on the percentage of total Reilly points contracted for the spatially differentiated policy scenario.

The *vertical axis* shows the parameters and corresponding impact in changing parameter values on the percentage of total contracted Reilly points. Only parameters that vary more than 10% from the default simulation results are displayed. Other parameters are not shown as they show little sensitivity to changes in parameter values. The *horizontal axis* shows the percentage change in total Reilly points on contracted AES-area. Figure 5.7 shows that especially parameters with respect grass production (mineralisation grassland, leaching coefficient grassland) are sensitive to variation in parameter settings. Furthermore, the size of the AES payment (€/ha) and the costs for buying cattle feed show to be sensitive to variation in parameter settings. These parameters have been addressed explicitly when simulating the results of this chapter.

5.5 Conclusion and Discussion

This chapter assesses the impact of alternative AESs on the spatial explicit rural landscape, while focusing on biodiversity conservation and capturing the heterogeneity between farmers as well as the spatial and institutional dynamics in land ownership and intensity of land use. The chapter shows how two different options of AESs for farmers to allocate parcels to biodiversity conservation result in different impacts from external disturbances, in this case fluctuating food market conditions. We add to the literature by translating individual farm behaviour to the landscape level; by providing insight into the spatial dynamics of land and land use using a resilience approach, and by including an ecological perspective through focusing on the development of biodiversity by the uptake of AESs. The resilience analysis shows how the two options of AES payments contribute in a different way to the spatial cohesion of the biodiversity conservation network, and thereby to the development of biodiversity in the area. The model can assist in the identification, design and evaluation of governance processes, in our case focusing on AESs. When imposing disturbances, both scenarios show differences in terms of resilience of the rural landscape. We now only focussed on ecological resilience for illustrative purposes, but to grasp the resilience of the coupled rural social-ecological system also economic and social aspects of resilience can be used for analysis. This type of full spectrum analysis of coupled social-ecological resilience falls outside the scope of this chapter, as it asks for more detailed modelling of social components, and socio-economic interactions. However, when looking at the development of the average farm income of farm agents in the model, it is interesting to see that in the spatially differentiated scenario a higher mean farm income is generated given the imposed output price disturbances. During periods of large price falls, farmers have the tendency to switch to contracting AESs as they try to secure their income by offering parcels for AESs. Under the spatially differentiated scenario, farmers are more willing to contract parcels that are close to nature conservation areas, because of higher payments given the total Reilly points contracted. We see that parcel size, parcel quality as well as distance to the homestead are decisive characteristics for farmers in their decision making process to offer, attract parcels or contract them under an AES. Small parcels with low quality that are situated further away from the farmstead are offered for AESs at a higher pace, when comparing to high quality large parcels located near the farmstead.

The two different types of AES governance structures simulated in this chapter inherent both the economic and ecological characteristics of the rural social-ecological system, taking into account both the economic rational behaviour of the farmers and the biophysical components of the system and therefore serves as a motivation to use these type of government interventions for analysis. So far we did not consider the effects of AES contract duration on the simulation results, however this is an important topic for future research, because parcels brought under AES may need approximately 5-10 years of specific management to gain enough in abiotic quality that they fully contribute to the regional habitat network. Frequent switches between food market and biodiversity aims do not provide enough development time. From a socio-economic perspective, contracts with larger duration provide income certainty, but also decrease the flexibility of farm management. Another important issue we did not analyse are the implications for biodiversity of gaining more spatial cohesion but losing total area. The spatially differentiated payment will be more beneficial to plant species and less mobile insects, but less beneficial to birds and mammals. Such an analysis requires more spatial detail and additional ecological modelling, which is outside the scope of this chapter.

Further developments of the model are desirable to improve the practical use of its results for policy development. Examples of such improvements are related to the farm agents behaviour and the spatial configuration of AES area in the model. A caveat is that potential public and private transaction costs of schemes (see Mettepenningen et al., 2011) are not taken into account. With regard to the farm agent's behaviour, their behaviour is limitedly rational, meaning that the decision making process of the farm agent is path dependent, and not globally optimizing. It would be interesting to experiment with different farm behavioural models, representing different types of farms. With respect to the spatial configuration of AESs in the model, it would be a valuable model extension to let loose the assigned locations of parcels for AESs. It would be interesting to see what the behaviour of farm agents will be whenever all parcels in the case study area could be contracted. Furthermore, stochasticity can be introduced in the model by adding random numbers which can be combined with probabilities to simulate trade-offs in the farm agent decision making process. We also should mention that the landscape cohesion method used in this chapter is pretty rough and should not be used when there is a lot of detail required on i.e. the role of habitat quality of particular species. By using the proposed method, much detail is exchanged for simplicity and generality. However we think that, for the purpose of this chapter which aims at gaining understanding in the interactions between socio-economic and physical components in the rural landscape, this method is sufficient.

Appendix 5A

The Reilly index derives from Newton's law of gravitation, where gravity is stronger for larger 'bodies' and gravitational strength is inversely related to the distance between 'bodies'. It was originally applied to the study of retail markets (Reilly, 1931), to reflect the attractiveness of different retail areas (cities) in terms of the trade-off between consumers' travel costs and the size of alternative retail areas. We modify the Reilly index to calculate the impact of surrounding nature conservation areas on the potential for biodiversity conservation by sites with AESs. Rather than distance to urban centres, we employ distance to nature conservation areas. Instead of population, we use the size of the nature conservation areas (measured in squared meters). Equation (1) gives the formula for the calculation of the spatial cohesion Reilly-index. The calculation of the spatial cohesion Reilly-index starts at the point where the site is located. After that, the size of the nature conservation areas (abbreviation NCA) within a certain radius (i.e. 5 km) is determined, as well as the size of the AES site. Based on the sum of all the distances of the site to the nature conservation areas located within the chosen radius, and on the size of the nature conservation areas and AES sites, the spatial cohesion Reilly-index can be calculated:

$$R_i = \sum_{j=1}^{J} \frac{A_i + C_j}{d_{ij}^2} \qquad (1)$$

where R_i represent the Reilly index of parcel i, A_i the surface area of parcel i, J the number of conservation areas within range, C_j the surface area of the j^{th} nature conservation area, and d_{ij} the distances from the parcel to the centres of the conservation areas. The index captures, in one number, the size of the nature conservation areas in proximity to the AES site, and the distance from the site to the nature conservation areas (Cotteleer, 2008). Strong points of the spatial cohesion Reilly-index are the combination of distance with size, and the fact that nature conservation areas located further away or which are smaller in size are weighted less. As such, the spatial cohesion Reilly-index is a measure for the share of land used for a certain land-use function in the surroundings of a specific location.

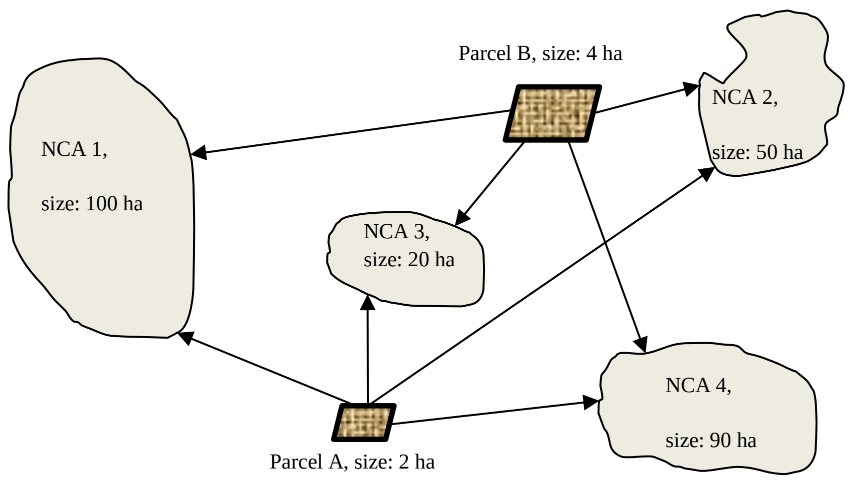

Figure 5A.1: Graphically presentation of the spatial cohesion Reilly-index
Source: adapted from Cotteleer (2008) and adjusted.

We illustrate the calculation of the spatial cohesion Reilly-index in Table 5A.1 and Figure 5A.1 for the location of two AES-sites: A and B. The two sites (A and B) are heterogeneous in size and are situated in the proximity of four different nature conservation areas. The size of the four nature conservation areas is also given. Figure 5A.1 shows the two sites, and their location in relation to the four NCAs. The arrows in Figure 5A.1 give the distance to the four nature conservation areas. The size and distance correspond with Table 5A.1.

Table 5A.1: Spatial cohesion Reilly-index for two AES sites given the size of sites and NCA and the distance to the NCA

NCA	NCA size (m^2)	Size site A (m^2)	Distance to site A (m)	Size / $(Distance)^2$	Size of site B (m^2)	Distance to site B (m)	Size / $(Distance)^2$
1	1,000,000	20,000	1,000	1.02	40,000	1,400	0.53061
2	500,000		2,100	0.11791		400	3.375
3	200,000		600	0.61111		700	0.4898
4	900,000		1,200	0.63888		900	1.16049
Spatial cohesion Reilly-index			2.38791			5.5559	

Source: Adapted from Cotteleer (2008, p.101) and adjusted.

From Table 5A.1 and Figure 5A.1, it is apparent that for site B, the spatial cohesion Reilly index is much larger than for site A, because site B is located closer to two of the nature conservation areas. Although NCA 2 is not the largest area, the shorter distance from site B to this area is largely responsible for the larger spatial cohesion Reilly score for this site. From this theoretical example, it can be seen that an AES site located near or in a NCA, has a higher spatial cohesion Reilly-index than a site that is located further away. Also larger sites result in a higher spatial cohesion Reilly-index when compared with smaller sites.

6. Measuring resilience in rural social-ecological systems: An agent-based modelling approach

Schouten, W. M. van der Heide, W. Heijman, P. Opdam, N. Polman. E. Westerhof. 2013. Measuring resilience in rural social-ecological systems: An agent-based modelling approach. Submitted to Ecological Economics.

Abstract

The concept of resilience is widely promoted as a promising notion for the management of social-ecological systems. However, resilience is usually explored as a theoretical construct, due to its abstract and multi-dimensional nature. To be able to use resilience in the management of rural areas, the concept needs to be made operational and measurable. This chapter explores the potentials and limitations of operationalizing resilience in rural social-ecological systems through measurable indicators using a spatially explicit agent-based model as simulation tool for their behaviour. We demonstrate this approach by comparing two experiments with management regimes based on rules of self-governance versus hierarchical governance, and measure how disturbances affect the resilience indicators. Results illustrate how operationalization of resilience into measurable indicators helps to guide the development of management strategies that focus on building resilience.

6.1 Introduction

Rural areas are increasingly changed by drivers on large spatial scales such as economic globalization (or global economic integration) and climate change (Olesen and Bindi, 2002; Pedroli et al., 2007). These international drivers may bring forth abrupt disturbances, such as high output price peaks and falls, floods and droughts, and massive outbreaks of animal diseases (BSE, avian influenza). These disturbances can be disruptive to the development and management of rural areas. To understand such effects, approaches are needed that look at rural areas from a complex system perspective, taking into account the interdependence between ecological and socio-economic dynamics. Rural areas are considered as a social-ecological system (SES), characterized by strong links between the social and the ecological component, and by multiple interactions across spatial and temporal scales (Berkes, 1998; Cumming, 2011). The behaviour of complex systems is highly unpredictable, and the effects of disturbances can therefore be highly uncertain. In this context, resilience has been promoted as a concept to guide the management of SESs (Plummer and Armitage, 2007).

Resilience is a system property that reflects the capacity of a system to absorb disturbance, undergo change, and still retain the same essential functions, structure, identity and feedbacks (Carpenter et al., 2001; Holling, 1973). Over the past decade, resilience has been analysed in a variety of interdisciplinary research. With respect to the specific case of rural SESs, resilience has received considerable attention in scientific literature on social, economic and natural resource management aspects (see e.g. Darnhofer et al., 2010; Van Apeldoorn et al., 2011; Cabel and Oelofse, 2012; Wilson, 2010). Usually, these studies explore resilience as a metaphor or theoretical construct, because it is difficult to measure due to its abstract and multidimensional nature. However, to be able to use resilience in the management of rural areas, the concept needs to be made operational and measurable (Cumming et al., 2005). Cutter (2008) states that ‘despite various attempts for describing and assessing resilience, none of the metaphorical and theoretical models have progressed to the operational stages where they effectively measure and monitor resilience at the local level’. Only a few studies empirically operationalize the concept in real-world systems, using system-specific definitions of resilience that are not all measurable (see e.g. Schlüter and Pahl-Wostl, 2007; Schlüter et al., 2009; Janssen and Carpenter, 1999; Leslie et al., 2009). Therefore Bennett et al. (2005), Cabell and Oelofse (2012), Carpenter et al. (2001) and Cumming et al. (2005) proposed monitoring measurable criteria of the system that can be considered as proxies (indicators) for the resilience of the system.

In this chapter we apply this approach to the rural SES by using a list of criteria for resilience proposed by Walker and Salt (2006). Schouten et al. (2012a) transformed this list into a framework for evaluating implications of rural development policies for the resilience of rural areas. Taking the evaluation framework as a starting point, this chapter focuses on translating the resilience criteria into measurable indicators. The way these indicators behave in a rural SES in times of disturbances will be tested using an agent-based modelling (ABM) approach. Modelling human decisions in SESs by means of an ABM approach has become a popular tool that has been employed over the past decades to understand system complexity and non-linear behaviour (see Schlüter et al., 2012 for literature overview). For this chapter we make use of a spatially explicit rural ABM, which has been applied earlier by Schouten et al. (2012b, 2013a), to gain insight into the way farmers and the environment in rural SESs respond to disturbances. We apply this model on a case study of biodiversity conservation in a small-scale dairy region in the eastern part of the Netherlands, namely Winterswijk.

Our goal is to explore the potentials and limitations of operationalizing resilience in rural SESs through measurable indicators, by testing their behaviour in times of disturbances. This insight can be useful for rural policy makers and managers to develop and evaluate strategies that focus on enhancing or reducing particular system properties as disturbances occur. Building on the work of many researchers who have identified criteria for resilient SESs, we contribute to the operationalization of these criteria by explicitly measuring them at the local level. To illustrate the applicability of the indicators we compare two experiments with simplified management regimes based on rules of self-governance vs. hierarchical governance, and measure how output price disturbances affect the resilience indicators.

The chapter proceeds as follows. In Section 6.2, we describe the methods that we use to operationalize resilience. After specifying the resilience criteria, we discuss the way we operationalize the resilience criteria into measurable indicators. This is followed by a description of the general structure of the applied ABM and the social-ecological system that serves as a case study for this exercise. Section 6.3 then introduces the two experiments that will be conducted. Section 6.4 discusses the results of the experiments and Section 6.5 discusses the suitability of this approach for the operationalization of resilience in rural SESs.

6.2 Methods

In this section we discuss the conceptual foundations of the way we attempt to operationalize resilience in rural SESs. First, we discuss the characteristics for a resilient SES, and their application to the rural case. Secondly, we operationalize the characteristics into measurable indicators and describe the case study. Third, we discuss the structure of the agent-based model used to simulate the indicators behaviour.

6.2.1 Operationalizing resilience criteria into measurable indicators

Walker and Salt (2006) monitored nine criteria of a resilient SES, which cover the broader themes that revolve around humans existing within SESs: diversity, variability, modularity, acknowledging slow variables, tight feedbacks, social capital, innovation, overlap in governance, and ecosystem services. Schouten et al. (2012a) translated these criteria to the case of rural SESs for evaluating how rural development policies contribute to resilience in European rural areas. They experienced some important difficulties when translating the resilience criteria into rural specifications for the policy evaluation framework. Some criteria show significant overlap (e.g. modularity and tight feedbacks), and some criteria are difficult to monitor because they are not scaled to a time or spatial dimension (e.g. different levels of governance and slow variables). As a result, Schouten et al. (2012a) conclude that not all resilience criteria can be operationalized in a quantitative way, and that qualitative approaches are more appropriate for some of the criteria. Based on this conclusion and given the purpose of this chapter, we limit our approach to criteria that are quantifiable into measurable indicators. Furthermore, the SES that is used as a case study in this chapter, and the spatially explicit ABM that will be discussed in Section 6.2.2 also have their limitations with respect to monitoring measurable indicators. Therefore we selected two of the resilience criteria that Walter and Salt (2006) introduced: ‘diversity’, that in our study encompasses biological diversity, diversity of income sources and farm diversity, and ‘social capital’, which can be interpreted as the existence of networks between rural stakeholders. Furthermore, we add an additional criterion to the list that Walter and Salt (2006) omitted, but from which we believe is of crucial importance for the resilience of rural SESs: average farm income (see also Jetté-Nantel et al., 2010).

Diversity

Diversity plays a crucial role in developing resilience because system components can replace or compensate each other in times of disturbances (Walker and Salt, 2006). With respect to the rural SES, Schouten et al. (2012a) distinguished three specifications: diversity under the ecological system (biodiversity), diversity under the socio-economic system (diversity of income sources and farm diversity), and diversity of ecosystem services delivered from the ecosystem to the socio-economic system. The way we operationalized these specifications will be described in the following three subsections.

Biodiversity

Biodiversity will be operationalized by means of a spatial cohesion Reilly index (see Schouten et al., 2013a for method), which is a proxy for the potential contribution of parcels of land to conserve biodiversity, thereby taking into account their spatial configuration in the surrounding landscape. We calculate the impact of surrounding nature conservation areas on the potential of the parcel for biodiversity conservation. The distance to these areas, and their size is taken into account while calculating the number of 'Reilly points'. The assumption behind this reasoning is related to the concept of spatial cohesion of habitat networks at landscape level. The spatial cohesion concept implies that the number of species finding sustainable conditions in the regional landscape increases with the size and environmental quality of the network elements and the degree of connectivity in their pattern (Opdam et al., 2008; Opdam et al., 2003).

Diversity of income sources

The second rural specification that relates to diversity is the 'diversity of agricultural goods and services'. Darnhofer (2010) and Reidsma and Ewert (2008) stated that on-farm diversification is an indicator for resilience, because if farmers diversify their on-farm activities they are not solely dependent on primary agricultural production, so that their income would fluctuate less, thereby increasing their economic persistence. Examples of these multi-functional agricultural activities are farm camp sites, on-farm processing, care activities and energy production. Diversity of income sources will therefore be operationalized by focusing on the diversity in farming activities. We calculate the share of the mean farm income generated by activities other than primary agricultural production for each farmer in the case study.

Farm diversity

The third indicator for diversity is the diversity among farm types at the regional level (e.g. differences in farm intensity and farm size). Greater diversity in farm types is believed to increase the ability of the rural SES to withstand disturbances because multiple management strategies are available in the area that respond to disturbances in their own way (see e.g. Reidsma and Ewert, 2008). For this chapter we operationalize farm diversity by looking at the distribution of farm sizes in hectares in the case study. We obtain an indicator for farm diversity by comparing the farm sizes of the farm population in the five policy scenarios that are discussed in Section 6.3.3, and test their significance.

The third specification of diversity suggested by Schouten et al. (2012a), which is the diversity of ecosystem services delivered by the ecosystem to the socio-economic system, will not be operationalized because of limitations of the spatially explicit ABM that we use (see Section 6.2.2).

Social capital
Social capital, which can be seen as 'the shared knowledge, understandings, norms, rules, and expectations about patterns of interactions that groups of individuals bring to a recurrent activity' is another important component in the process of building resilience in rural SESs (Ostrom, 2000, p.176). Rural communities that are strongly connected in tight social networks are assumed to have an increased capacity to respond to disturbances (Wilson, 2010). In these communities, transaction costs are lower, and the costs for enforcing contracts and monitoring are smaller. Knowledge and expertise are more easily exchanged than in low trust communities, and due to the social safety net that the network provides, people might become less risk-averse. At the same time, however, social capital can obstruct development, as strong homogeneous communities may discourage individual innovation and exchanges with 'the outer world' (Di Falco and Bulte, 2011). Thus, depending on its nature, social capital is an important supporting or obstructing ingredient for resilience in rural SESs.

For the purpose of this chapter, we operationalize social capital in two ways. Firstly by measuring the number of operating farms in the case study area, because we assume that a certain population size is needed to maintain a viable social network. Secondly by focusing on the participation of farmers in networks of civic engagement by measuring number of interactions between farmers and an environmental cooperative, which is a form of self-governance in the case study area (see Section 6.3.1). This is done by measuring the proportion of AESs contracted (see Section 6.3.2) and by counting the number of exchanged greening permits (see Section 6.3.3) between farmers. Higher participation in these networks is an indicator for higher levels of social capital, and thereby also for resilience (see e.g. Polman and Slangen, 2008; Beugelsdijk and Van Schaik, 2005).

Farm income
Where diversity of income sources is frequently discussed in resilience literature as a way to enhance resilience of rural SESs (Darnhofer, 2010; Walker and Salt, 2006), less attention is given to the welfare of rural households. Although diversity of income sources increases the welfare of rural households, it does not reduce farm income risk per se (Jetté-Nantel et al., 2010). No reference is made to a minimum size of these income sources needed to maintain a viable farm population, and a minimum standard of living in rural SESs. Therefore we propose an additional criterion, namely 'farm income', which is operationalized in this chapter by looking at the development of the average farm income for all operating farms in the rural SES.

6.2.2 The ABM model
Now that we have operationalized the resilience criteria into measurable indicators, we shall test how these indicators behave in a rural SES while being exposed to disturbances. We test this by using an agent-based modelling (ABM) approach. In literature, the modelling of SESs for resilience research is increasingly focused on human behaviour, and the way actors adapt to variable and changing resource conditions (Schlüter et al., 2012). Examples of studies on complex systems research using an ABM approach are Schlüter et al. (2009), and Schlüter and Pahl-Wostl (2007) focusing on the impact of

different governance structures on the use of water resources and Leslie et al. (2009) experimenting with environmental disturbances and their influence on the provision of ecosystem services. We use the model by Schouten et al. (2012b, 2013a), which focuses on assessing the impact of agricultural policy support measures that are part of the EU Common Agricultural Policy on the rural SES, taking into account both microeconomic farm management theory and modules for simulating biophysical dynamics. The modelled rural SES is composed by an ecological component – containing nature areas, potential areas for biodiversity purposes and conventional agricultural land – and a socio-economic component, that is composed by farm agents using the conventional agricultural parcels to let their cows graze, produce grass and maize as fodder crops, and as manure disposal area.

Figure 6.1 shows that the model consists of an *initialization module,* a *farm module*, an *agri-environment module*, a *land lease market module*, a *7% Ecological Focus Areas (EFAs) exchange module* and an *output module*. We will discuss the different modules in more detail below.

- For the *initialization module,* individual farms (in the case study area Winterswijk discussed in Section 6.2.3) are distinguished, each of which are taken from the Agricultural Census (reference year 2010)(CBS, 2011). The attributes on the farm level are the farm structure, given in age of the farmer, type of farm, size and number of total owned and rented parcels. At parcel level, attributes are crops grown, soil quality, crop suitability, information on ground water tables and land use which were used to integrate the production criteria of individual parcels in the model. These criteria are derived from Cadastral GIS-maps. At landscape level, attributes are number of farms in the region, spatial land criteria (nearby National Ecological Network nature areas), size and distance from the parcel to the agent's farmstead.
- In the *farm module* each farm agent is equipped with a behavioural model that guides decisions and the model keeps track of the agent's internal state described by attributes such as age, location and size. According to their behavioural models, the individual farm agents evolve subject to their current state of attributes and to changes in their environment.
- The results of the farm module serve as input for the *agri-environment module* in which farmers make choices on whether to contract parcels to enhance farmland biodiversity (so-called agri-environment schemes, see Section 6.3.2), keep conventional farming, or offer their parcels to other farmers.
- The results of the agri-environment module serve as input for the *land lease market module*. In this module parcels of land are reallocated by means of an auction that matches bids and asks based on creation of the largest buyer/seller surplus.
- Then, the results of the land lease market module and the farm module serve as input for the *7% EFAs exchange module* which is another policy aiming at conserving farmland biodiversity. Further elaboration on the decisions made in the 7% EFAs exchange module will be given in Section 6.3.3.
- Finally, the function of the *output module* is to keep track of the changes in the region with respect to farming structure, agri-environment schemes and 7% EFAs measure and conditioning of the model results for the next simulation period. Results on the farm level (such as e.g. age and revenue from production) as well as on the landscape level (such as land use) are used to update farm attributes and regional attributes in the next period. These outputs of the model are used to measure the resilience indicators discussed in Section 6.2.1.

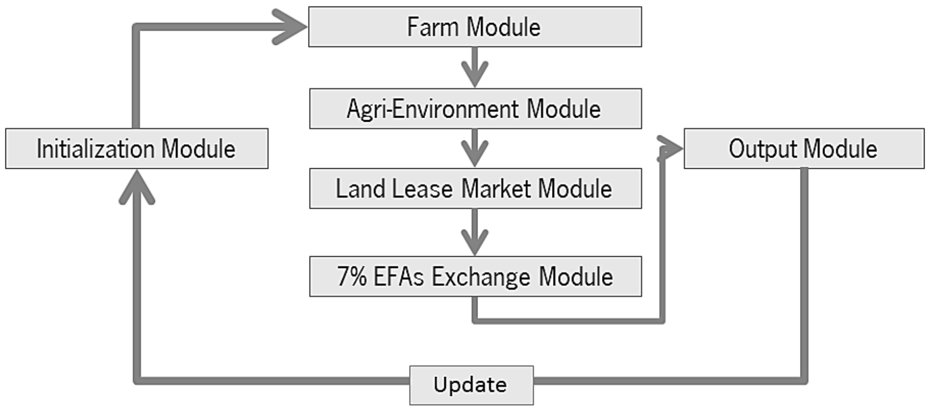

Figure 6.1: Course of events during one simulation period

The *agri-environment module* and the *7% EFAs exchange module* can be switched on and off.

6.2.3 The social-ecological system: rural landscape Winterswijk

For this chapter we use the agricultural region Winterswijk, which is located in the eastern part of the Netherlands, as a case study. From a landscape perspective, the area represents a highly valued cultural-historic landscape where small-scale agriculture and nature areas are closely related. This spatial structure has resulted in a synergic development between nature conservation, social and economic development and recreational and cultural fruition (Provincie Gelderland, 2005). The size of the area is approximately 22,000 ha, in which 634 farms are present (reference year 2010). The rural SES that is used for this chapter is characterized by 201 specialized dairy farms that were selected from Agricultural Census data. Together, these farms use approximately 60% of all agricultural land present in the area. Large parts of the region contain important nature conservation areas that belong to the National Ecological Network (NEN), which is part of the European Natura 2000 network (Opdam et al., 2008). Figure 6.2 shows the boundaries of the agricultural region (‘national landscape area’), and shows where the nature areas and the potential areas for farmland biodiversity conservation (‘search area’) are located.

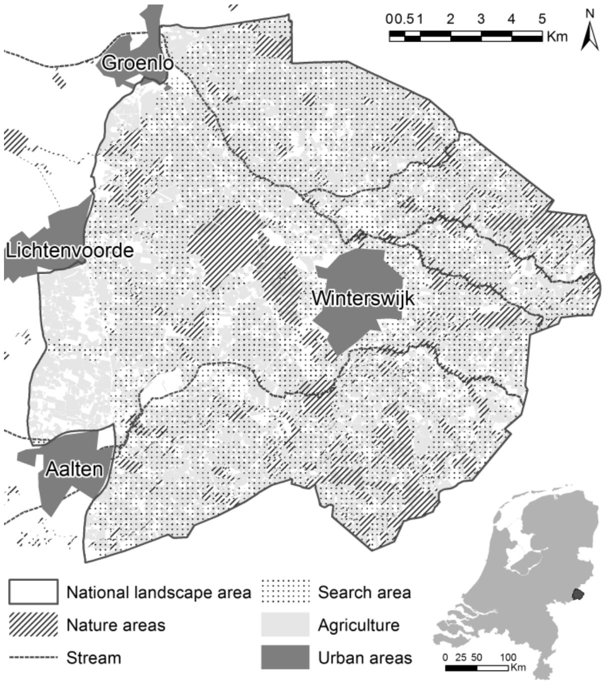

Figure 6.2: The case study area Winterswijk

Figure 6.2 shows that nature areas are scattered throughout the case study area, and that potential areas for farmland biodiversity are closely linked to these nature areas. Areas not included in the model are white and include small villages. The main urban areas are indicated in dark grey with the city of Winterswijk located in the center.

6.2.4 Imposed disturbances: Increased volatility in milk prices

To simulate how the rural SES responds to disturbances, we choose to introduce output price disturbances, specifically milk price disturbances, to the actors in the rural area. The choice for milk price disturbances is based on the characteristics of the study area, in which dairy farming is a dominant form of land use (see also Schouten et al., 2013a). Revenue from milk production is of high relevance to dairy farmers in this region, as they currently rely to a large extent on these milk prices as their main source of income. We impose milk price disturbances to the farm agents in the area by allowing milk prices to fluctuate over a period of six years (given a 25-year simulation period). Milk price disturbances set in after ten periods, and last until period 15, to prevent possible disorders due to the warm-up time of the model in the first part of the simulation. Simulation length and warm-up time can be edited.

6.3 Introducing two experiments

6.3.1 Justification of the experiments and management regimes

To explore how the resilience indicators respond to the milk price disturbances, we designed two experiments in which we apply simplified management regimes based on different governance rules (self-governance vs. hierarchical governance rules) for managing farmland biodiversity. Farmland biodiversity is increasingly recognised in Europe, both in terms of its intrinsic and cultural value as well as the role it plays in providing essential ecosystem services (Poláková et al., 2012). It is discussed throughout resilience literature as an important prerequisite for the resilience of its species, its ecosystems and the physical environment on which farmers depend for their agricultural production (Tscharntke et al., 2005; Kampmann et al., 2012). As such, enhancing farmland biodiversity can be considered as strengthening resilience of the rural SES.

With respect to the two management regimes, Lebel (2006) states that the capacity of a SES to manage resilience resides in its actors, social networks and institutions. Our interest in the effect of those management regimes on the rural SES is motivated by the hypothesis that moving away from the traditional way of steering rural development policies through hierarchical governance towards self-regulation in which the main actors are organizations and collective interests can ultimately make the system more flexible and adaptive to disturbances and thus enhance resilience (Glasbergen, 2000; Lebel, 2006). In the context of hierarchical governance, the main actors are governments, while in the context of self-governance, the central role is played by organizations of collective interests. We focus on a specific form of self-regulation: the environmental cooperative, which is a regional organization in which farmers collaborate to integrate environmental values into their production process. Jongeneel et al. (2008) and Polman and Slangen (2008) hypothesize that execution of agri-environment policies by environmental cooperatives will be more effective and efficient compared to centrally steered policies due to a reduction of transaction costs, present mechanisms to countervail opportunistic behaviour, local expert knowledge etc. In the following two subsections, the two experiments are presented in more detail as well as the way we implemented the two management regimes.

6.3.2 Experiment 1: Agri-environment schemes

Agri-environment schemes (AESs) are an example of how governments provide measures for farmers to preserve biodiversity. Traditionally, AESs in the EU are organized by the government (hierarchical governance). Farmers receive a compensatory payment whenever they commit themselves voluntarily for a given period to deliver agri-environmental services on all or part of their land independent of the location and spatial configuration of the landscape (Whittingham, 2011). In the proposals for the CAP 2014-2020 the use of environmental cooperatives for the execution of AESs is encouraged, with a clear reference to their role in increasing efficiency and effective rural development (EC, 2011a).

For this experiment we compare a hierarchical governance scenario (1A, current situation), in which all farmers receive a fixed compensatory payment per hectare, independent of location and spatial configuration of the parcel, with a situation in which the environmental cooperative arranges the contracts based on their knowledge of where farmland with potential high biodiversity is situated for the whole case study area (scenario 1B). We assume that the environmental cooperative has expertise on where parcels with high potential biodiversity are situated. In the model, the environmental cooperative maps each year where the grassland parcel with highest added value to biodiversity are situated based on the Reilly points discussed in Section 6.2.1. The environmental cooperative consults the particular farm agents and offers a compensatory payment based on the contracted Reilly points for the particular parcel, so that the parcel can be contracted with an AES. The farm agent, in turn, makes a trade-off between continuing conventional farming, contracting an AES and thereby facing decreasing yields, or offering the parcel to the land market because of high opportunity costs. We assume that the success of the environmental cooperative is not entirely due to the compensatory payment, but that they raise recognition among farmers to deliver benefits for biodiversity, and resulting landscape amenities. This recognition is reflected in the model by assuming that the environmental cooperative pays an extra bonus, on top of the compensatory payment, compensating the loss of income. Other types of bonus are possible but not taken into account. In the model we assume that AESs are signed for a period of six years, and can only be applied to grassland parcels. Maize land parcels are only used for feed production and manure disposal. For both management regimes, a budget is assumed equal to the eligible AES area (denoted as 'search area' in Figure 6.2) times the current compensatory payment per hectare (1065 euro/ha).

With respect to the resilience indicators discussed in Section 6.2.1, we hypothesize that the environmental cooperative (scenario 1B) with its tailor-made approach is better able to generate biodiversity than a hierarchical governance regime (scenario 1A) given the same budget restrictions. For diversity of income sources we expect that farm agents are able to generate more income from farm diversification when the environmental cooperative is present, as probably more hectares will be contracted with AESs due to the recognition that is raised among farmers to deliver biodiversity benefits. We also expect that this will lead to an increase in average farm income. With respect to farm diversity, we expect that there will arise a dichotomy between small-scaled farms focusing on diversification executing AESs, and large-scale farms focusing on producing agricultural products for the world market. For social capital we expect that more farm agents will survive because they are able to diversify their income sources with AESs. Furthermore we expect that the environmental cooperative will succeed in increasing recognition among farmers to execute AESs, leading to higher participation of farmers in the environmental cooperative which is reflected by the larger number of hectares contracted with AESs.

6.3.3 Experiment 2: The Ecological Focus Areas measure

The second experiment focuses on a measure that obliges farmers to convert 7% of their land for biodiversity purposes, which are so-called 7% ecological focus areas (EFAs) aiming at the preservation of ecological reserves and landscapes. This measure is part of the European Commission proposals for the CAP 2014-2020 (EC, 2011b). The obligations can be met by setting aside arable land, left to lie fallow, or by using buffer strips, landscape features, afforested areas and terraces. Currently, there is an on-going debate on how to imply the 7% EFAs measure in the most effective and efficient way. One of the discussions is about whether environmental cooperatives are allowed to facilitate the implementation of the 7% EFAs measure at a local level. For this chapter we will compare a hierarchical governance regime, in which all farmers are obliged to convert 7% of their agricultural land for biodiversity purposes (scenario 2A) with a situation in which the environmental cooperative plays a facilitating role in the area (self-governance regime; scenario 2B).

In the self-governance regime, the environmental cooperative facilitates exchange between farm agents. In the model we simulate this facilitating role by introducing a market for so-called 'greening permits' (see also Schouten et al., 2013b). A greening permit represents the obligation to convert one hectare of land for biodiversity purposes. The exchange of greening permits is represented by a perfectly competitive market in which multiple demanders and suppliers are active at the same time. Farm agents receive a payment for applying conservation for the extra 7% EFAs hectares. In this chapter we assume that the environmental cooperative institutionally organizes this market. Bids are collected by the environmental cooperative and are matched with the offers based on the highest price. Collected permits are valid for one year and are only applied to grassland.

We hypothesize that when the environmental cooperative facilitates exchange of greening permits between farm agents, more biodiversity will be generated. We expect that farm agents with relatively many parcels with low productive capacity (due to low soil quality or large distance from the homestead) will attract more greening permits, which leads to a clustering of 7% EFAs parcels, resulting in higher Reilly points per parcel. With respect to diversity of income sources, we expect only minor changes at a regional level as an income transfer takes place from farm agents that offer a greening permit, to farm agents that attract greening permits and perform extra 7% EFAs hectares on their land. This means that on a regional level, the total income remains the same. The same result is expected for the average farm income indicator.

With respect to farm diversity, we expect that the same situation will appear as is expected for experiment 1: we expect a dichotomy between small-scale farms focusing on diversification executing 7% EFAs, and large-scale farms focusing on producing agricultural products for the world market. For social capital we expect that fewer operating farms will be left in the case study after the 7% EFAs measure is introduced, because high productive agricultural land is taken out of production (see also Westhoek et al., 2012). We would expect the exchange of greening permits to lead to a softening of this effect, as the 7% EFAs are allocated more effectively and efficiently in the case study area. We measure the participation of farmers in environmental cooperatives by looking at the number of exchanged greening permits in the area. We expect that large numbers of exchanges will take place, when compared to the total farm population in the area.

Each scenario is compared with a scenario in which no policies are introduced in the model, denoted as ‘no policies’-scenario. The model is simulated for 25 time periods (corresponding to 25 years, considering one generation of farmers) starting in the base year 2010. Table 6.1 summarizes the two experiments and the main hypotheses.

Table 6.1: Summary of experiments conducted in this chapter and main hypotheses (↑ = increase; ↓ = decrease and ←→ no change)

Experiments	Policy scenarios	Hypotheses
1.Agri-environment measure	1A: *Current situation:* A fixed agri-environment payment is given, irrespective of spatial configuration of the parcel	• Biodiversity ↑ • Diversity of income sources ↑ • Farm diversity ↑ • Number of operating farms ↑ • Farm income ↑
	1B: *AESs environmental cooperative scenario:* Payment for agri-environment contract depends on the spatial configuration of the parcel, provided by the environmental cooperative	*Compared to 1A:* • Biodiversity ↑ • Diversity of income sources ↑ • Number of operating farms ↑ • Hectares AESs ↑ • Farm income ↑
2. Ecological Focus Area measure	2A: *7% EFAs own farm scenario:* 7% agricultural land taken out of production on own farm	• Biodiversity ↑ • Number of operating farms ↓ • Farm income ↓
	2B: *7% EFAs environmental*	*Compared to 2A:*

cooperative scenario: Farm agents are allowed to exchange 'greening permits' with other farm agents in the area.	• Biodiversity ↑ • Diversity of income sources ←→ • Number of operating farms ↑ • Farm income ←→

6.4 Results

Table 6.2 summarizes the results of the two experiments for the seven resilience indicators.

Table 6.2: Average value of resilience indicators for the 'no policies'-scenario, scenario 1A (current situation), 1B (AESs environmental cooperative scenario), scenario 2A (7% EFAs own farm scenario) and 2B (7% EFAs environmental cooperative scenario) for final year after a 25-year simulation period

Resilience criteria	Indicators	Unit of analysis	Policy scenarios				
			No policies	1A Current situation	1B AESs environmental cooperative scenario	2A 7% EFAs own farm scenario	2B 7% EFAs environmental cooperative scenario
Diversity	Biodiversity indicator (% contracted Reilly points)	%	0	11	65	8	8
	Diversity of income sources (% income generated from diversification)	%	0	63	76	0	4
	Farm diversity (variance average farm size in ha)	ha	51	48	50	50	50
Social capital	Size of social network (% of initial number of operating farms)	%	26	26	26	26	26
	Hectares contracted with AESs or EFAs	%	0	29*	72*	7**	7**
	Number of exchanged greening permits	nr	0	0	0	0	94
Farm income	Index average income per farm (No policies scenario = 100)	%	100	109	104	102	102

*percentage of total eligible AES-area, or search area denoted in Figure 6.2
**percentage of total area eligible for 7% EFAs, or land for agriculture denoted in Figure 6.2

6.4.1 Diversity

Biodiversity. In scenario 1B, in which the environmental cooperative assigns AESs, a higher percentage of Reilly points is generated as compared to the current policy of providing agricultural payments (scenario 1A). This is in line with our hypothesis for biodiversity effects. In the self-governance regime (scenario 1B), in which the environmental cooperative decides which parcels will be contracted based on the spatial cohesion in the habitat network, more Reilly points are generated, suggesting better conditions for increased biodiversity.

However, low levels of Reilly points are generated in scenario 2A and 2B. This means that whenever greening permits are exchanged from one farm agent to another, this does not necessarily result in more clustered habitat sites fostering biodiversity. An explanation for this result is that parcels can be converted for biodiversity purposes for the 7% EFAs measure in scenario 2A and 2B irrespective of their spatial configuration in the surrounding landscape. This is in line with the EC proposals (EC, 2011b). We conclude that the contribution of the measure to biodiversity could improve substantially if eligible parcels for 7% EFAs were to be dependent on their contribution to the spatial cohesion of habitat networks at landscape level.

Figure 6.3 illustrates the dynamics of the percentage Reilly points contracted for the four policy scenarios. The milk price disturbances are added to the figure for illustrative purposes.

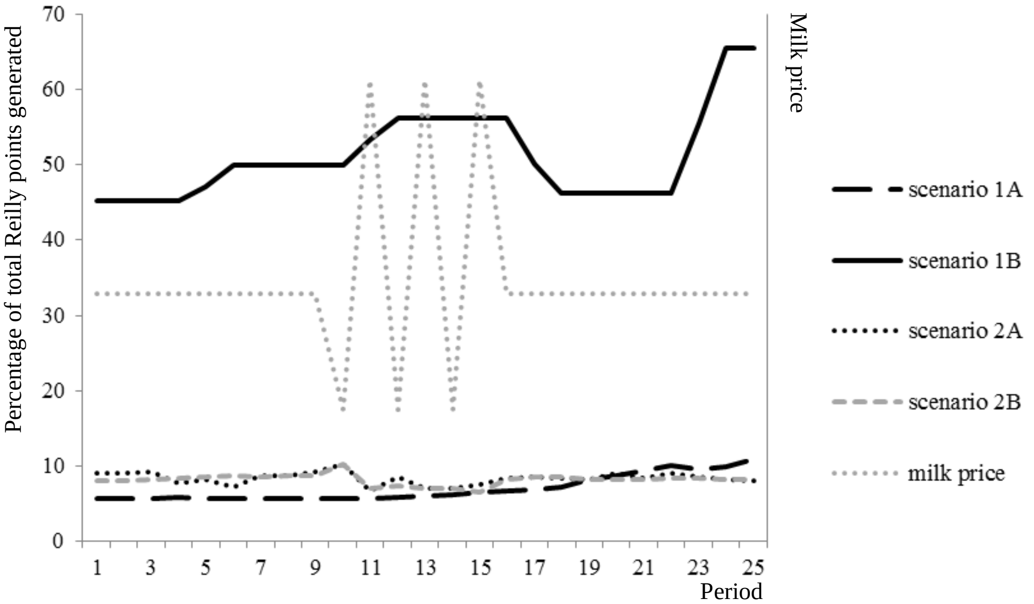

Figure 6.3: Development of percentage of total Reilly points generated for the four policy scenarios during a simulation period of 25 years while being exposed to milk price disturbances.

Figure 6.3 shows that scenario 1B (AESs environmental cooperative scenario) is more sensitive to milk price disturbances than scenario 1A (base scenario). During the milk price disturbances, farm agents try to buffer their income by looking for additional income sources. The higher compensatory payment that is given in scenario 1B persuades farmers to contract more parcels with AESs. The large increase after period 23 can be explained by the large number of farm agents that retires during that year. More land is available on the land market, and more land suitable for AESs is contracted.

Diversity of income sources (Figure 6.4 and Table 6.2) is highest in scenario 1B, in which the environmental cooperative arranges the AESs.

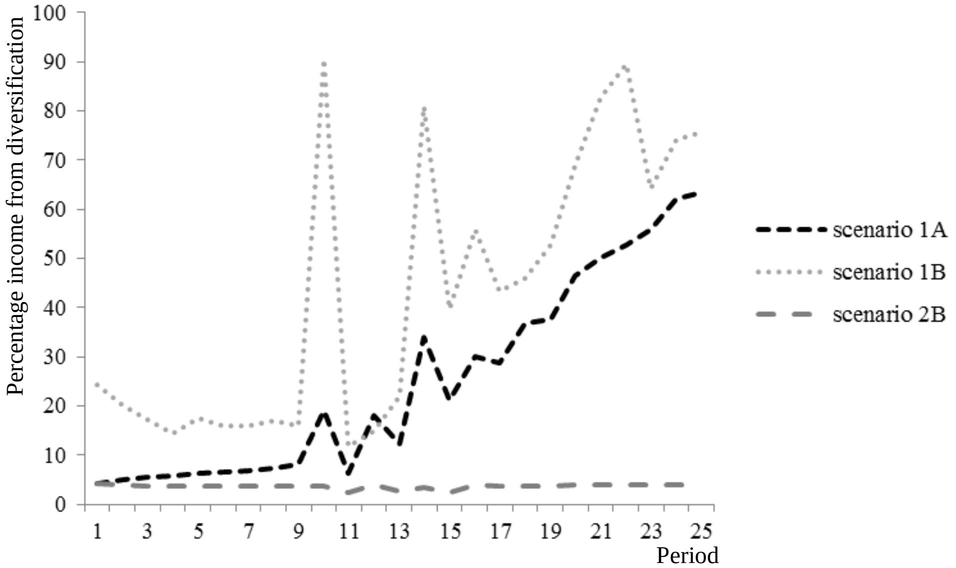

Figure 6.4: Percentage of income generated from diversification for scenario 1A (base scenario), 1B (AESs environmental cooperative scenario) and 2B (7% EFAs environmental cooperative scenario) given a milk price disturbance regime during a simulation period of 25 years

This is in line with the prediction that farm agents generate more income from diversification whenever an extra bonus is paid for parcels that contribute more to biodiversity. The larger volatility in scenario 1B is due to the fact that now parcels with high production value are also contracted for AESs. But whenever the milk price reaches a high peak, they are immediately converted into conventional agricultural use. The overall increase in income from diversification is explained by the increased number of available parcels eligible for AESs that are offered by farm agents that retire and stop their farm practice (see Figure 6.5). Only a small share of the farm income is generated from diversification in scenario 2B. This is due to an income transfer taking place from farm agents who offer a greening permit, to farm agents who attract greening permits. This transfer keeps the average farm income at a similar level.

The index of the average income per farm (Table 6.2) in the area also shows for all the scenarios an increasing development compared to the 'no-policies'-scenario. This overall increase can be explained by the assumption in the model that all farm agents try to attain the highest possible income during the simulation. The largest increase in average farm income is attained in scenario 1A. This can be explained by the fact that more farm agents can increase their farm income by making use of the AESs measure, because no selections take place by the environmental cooperative on parcels with the highest contribution to biodiversity.

Farm diversity (Table 6.3) varies significantly between the scenarios. Table 6.3 shows the results for the paired-samples t-tests performed for the farm sizes of the farm population in hectares, thereby comparing the 'no policies'-scenario with the four alternative scenarios.

Table 6.3: Paired* descriptive statistics and t-test results comparing average farm size in hectares between the 'no policies'-scenario and the four alternative scenarios after 25 simulation periods

Scenarios	M	SD	95% CL for Mean Difference	t	df
No policies	51.62	49.7	43.49, 59.75		
Scenario 1A	43.25	43.42	36.15, 50.35	12.56**	145
Scenario1B	50.43	47.92	42.59, 58.27	2.46**	145
Scenario 2A/2B	50.43	50.48	42.17, 58.68	3.45**	145

*Seven farm agents were omitted from scenario 1A, and one farm agent was omitted from scenario 1B, 2A/2B to create paired dataset
** $p < .05$

Table 6.3 shows that lower average farm sizes were detected, at the .05 significance level. The results for scenarios 2A and 2B were similar due to assumptions made in the model and therefore they are shown in one row. The largest decrease in average farm size was shown in scenario 1A. However, when looking at the development of the percentage of total number of operating farms in Figure 6.5, it is shown that scenario 1A results in the largest percentage of operating farms after a 25-year simulation period. When comparing these results to the results of Table 6.3, we conclude that the small farms survived in scenario 1A because of the introduction of the AESs-measure, and that smallholders have stopped their farm practices in scenarios 1B, 2A and 2B. Furthermore, the average farm sizes in scenarios 1B, 2A and 2B also significantly decrease, although the differences are small. In scenarios 2A and 2B, significantly higher standard deviations were observed, indicating a larger distribution of farm sizes in the population. This indicates a larger diversity of farm sizes in the farm population. When testing scenarios 1A and 1B with one another, it is shown that scenario 1B results in significantly larger farm sizes, with larger standard deviations than scenario 1A. When comparing scenario 1B with scenarios 2A and 2B, no significant differences in farm size are detected. It is shown that the AESs and the 7% EFAs measure significantly influence the distribution of farm sizes in the area. The large standard deviations in scenarios 2A and 2B indicate that more large farms are present in the area than in the 'no policies'-scenario, indicating a larger farm diversity.

6.4.2 Social capital

The number of operating farms (as a proxy for the size of the social network, Figure 6.5) declines steadily in all four scenarios. The main reason for this result is the demographic imbalance in the region. From agricultural census data for reference year 2010 we conclude that the average age for the 201 farmers in Winterswijk was approximately 51 years. Only twenty-four per cent of the farmers indicated in 2010 that they had a successor for their farm (Agricultural Census 2010, Ministry of Economic Affairs), meaning that 76% of the farms stopped farming within the simulation period. Therefore the largest decrease in operating farms is shown between approximately period 10 and 17. During this period, large numbers of farm agents retire, without having a successor.

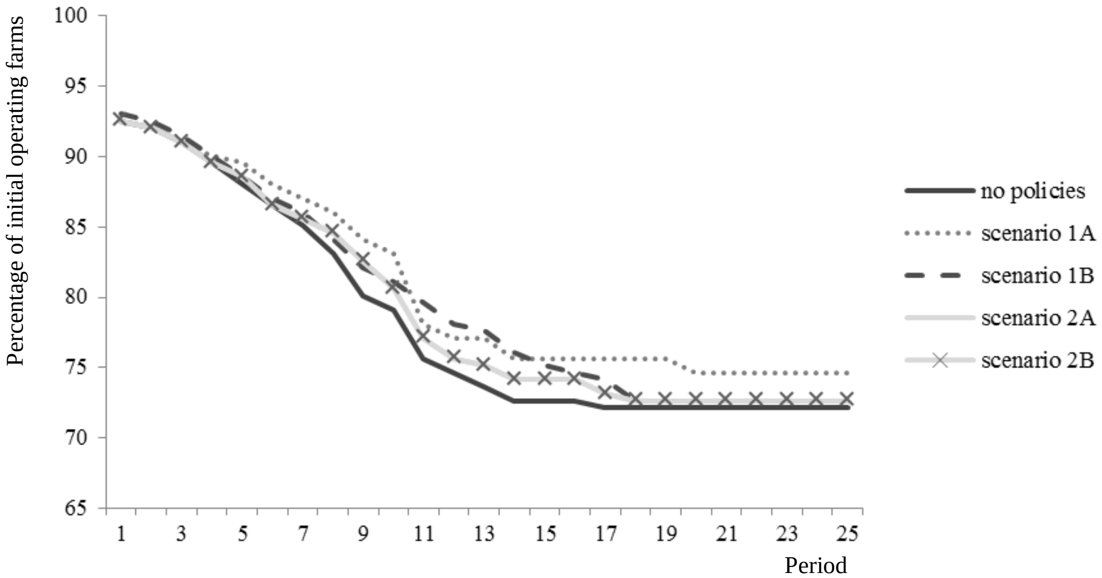

Figure 6.5: Percentage of initial number of operating farms in the area for the four scenarios for a simulation period of 25 years while being exposed to milk price disturbances (100%= 201 farms, reference year 2010)

In our model we assumed that no new farmers could start a farm practice, and neither could retiring farmers find a successor. Obviously, this leads to a decreasing number of operating farms in the region. In scenario 1A somewhat more farms keep operating after the 25-year simulation period than in the other scenarios. This is also what we expected in Table 6.1. The five scenarios in Figure 6.5 seem to stabilize during the last five years. This is due to the fact that by then the farm agents without successors have retired. However, their agricultural production and the possibility for 7% EFAs remains, as it takes some time to redistribute their land.

As a proxy for the level of interaction between farmers, the proportion of AESs contracted (Table 6.2) is shown to be higher when the environmental cooperative assigns AESs (scenario 1B). This is in line with our expectations as the environmental cooperative persuades farm agents to participate in AESs by providing an extra bonus whenever a parcel has a large potential contribution to biodiversity.

Similarly, the number of exchanged greening permits (Figure 6.6 and Table 6.2) shows that there is a large amount of exchange between farm agents in the model.

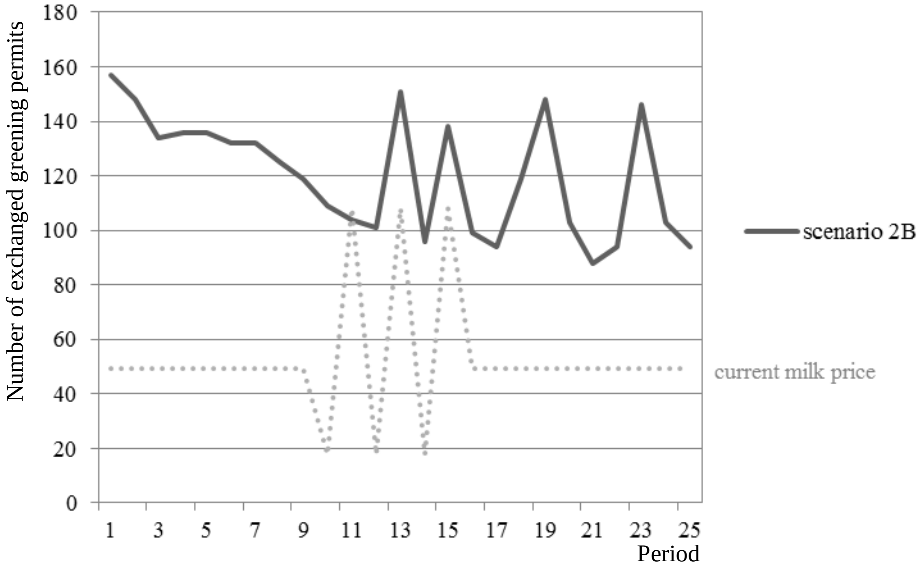

Figure 6.6: Development in the number of exchanged greening permits per year in scenario 2B (7% EFAs environmental cooperative scenario) while being exposed to milk price disturbances for a simulation period of 25 years

The number of exchanged greening permits starts to fluctuate strongly when milk price disturbances are imposed on the system. The main reason for this volatility is the large number of farm agents that retire in the second half of the simulation. Large numbers of parcels are offered to the land market, opening up the possibility for other farmers to exchange greening permits and convert new land for biodiversity purposes. Again we emphasize that parcels are converted for the 7% EFAs-measure in scenario 2B irrespective of their spatial configuration in the landscape.

The strong volatility in exchanged greening permits means that parcels managed for biodiversity often change in spatial configuration. Since such a parcel will be suitable for biodiversity after a development time of at least 5-10 years (which we did not incorporate into the model), the 2B scenario will not result in an increase in biodiversity as compared to the ‘no policies’-scenario.

6.5 Conclusion and discussion

This chapter explores potentials and limitations of operationalizing resilience in rural SESs through measurable indicators. How these indicators behave in times of disturbances is explored by using a spatially explicit agent-based model that captures both the socio-economic and biophysical dynamics of the rural SES. We illustrate the approach by comparing two rural policies aiming at biodiversity conservation while experimenting with two alternative management regimes, one based on rules of self-governance, the other on hierarchical governance rules. We followed how milk price disturbances affected the resilience indicators.

Results showed that some indicators are more informative than others, which is caused by a strong influence of the characteristics of the case study area, and of the assumptions built into the model. For the biodiversity and the farm diversity indicator, their behaviour showed to be influenced by the characteristics of the case study area. For the AESs-measure, the main reason for the departure from expectations was that nature areas are scattered throughout the case study area, and the area was shown to be rather homogeneous with respect to soil quality, which is why the expected clustering did not occur. For the 7% EFAs-measure, the behaviour of the biodiversity indicator was also influenced by the fact that in scenario 2B parcels can be converted for biodiversity purposes irrespective of their spatial configuration in the surrounding landscape. We conclude that the contribution of this scenario to biodiversity can improve substantially if eligible parcels for 7% EFAs were to be dependent on their contribution to the spatial habitat networks at landscape level. Case study characteristics also influenced the number of operating farms. Ageing of the farm population together with the small number of available successors dominated the decreasing trend of number of operating farms in the simulation. Also the way we modelled the farm agent decision-making played a role as we did not include the opportunity for new farm agents to start a farm practice, or the possibility to find a successor during the simulation. Furthermore, the assumptions built into the model strongly influenced the behaviour of the indicators. Therefore we performed sensitivity analyses for those parameters.

Unfortunately, a sensitivity analysis for the 7% EFAs measure has not yet been carried out and requires an extensive discussion which is out of the scope of this chapter. For the AESs policy scenarios, however, Schouten et al. (2013c) conducted an extensive sensitivity analysis. The results of this analysis showed that contracted AESs hectares, Reilly points, average farm income, and average farm size are most sensitive to changes in milk prices and to changes in the AESs compensatory payment. In this chapter, milk price fluctuations and AESs compensatory payments were kept within realistic ranges, based on data from the case study area, or from agricultural theory. It is expected, that if simulations were to be conducted using much larger values, the behaviour of the indicators would change. The results of the sensitivity analyses also suggested that the behaviour of the resilience indicators in response to milk price disturbances is influenced by the large number of interactions between parameters, and the inhabited conditional terms. The large number of interactions between parameters and conditional terms results in the fact that rather large milk price disturbances (above approximately 1 euro per kilogram) are needed in order to show sensitive behaviour of the resilience indicators.

Previously, Schlüter and Pahl-Wostl (2007), Schlüter et al. (2009) and Leslie et al. (2009) also applied an agent-based model to investigate the resilience of a particular SES. In comparison, we not only focused on ecological indicators for resilience, but also on social and economic components of the rural SES by including indicators on farm size, diversification, farm income, spatial configuration and social networks. Furthermore, our modelling approach of the natural environment and the socio-economic component included more detail. More specifically, with respect to the ecosystem, we include detailed maps on current land use, soil quality and crop suitability. The socio-economic component includes farm agents that are heterogeneous with respect to their farm characteristics: e.g. age, farm size, livestock, availability of a successor, and that are able to participate in social networks. Through the ABM and the monitored resilience indicators, we gain insight into the complex dynamics of the rural SES in times of disturbances. These insights can be valuable for rural policy makers and managers to evaluate to what extent rural policies contribute to resilience in rural SESs. For example Table 6.2 shows that scenario 1B achieved the highest score on six resilience indicators, with the exception of the average farm income indicator. Apparently, scenario 1B contributes the most to developing resilience in the particular rural SES. Monitoring data of resilience indicators can be used to evaluate how rural policies can strengthen these vulnerable parts. They can also be helpful in answering questions about conditions that stimulate the self-governing capacity of actors through local organizations and collective interests such as environmental cooperatives, aiming at creating sustainable rural development.

Further developments of the resilience criteria and measurable indicators are desirable, given that we managed to operationalize only three criteria represented by seven indicators in this chapter. In order to get a more comprehensive and measurable set of criteria, interdisciplinary research is needed that critically reviews the existing criteria, improves them, and develops new criteria and indicators. Up till now, the indicator for biodiversity focused on the contribution of parcels to the spatial habitat networks. Extending this indicator by including species population dynamics could provide more insight into the ecosystem dynamics during disturbances. The indicator for diversity of income sources was shown to be rather simplistic, as conducting AESs or 7% EFAs is the only way to earn income from diversification. It would be interesting to add additional farming strategies such as on-farm processing, farm camp sites or energy production. Furthermore, it would be interesting to experiment with alternative disturbance regimes, to see if the resilience indicators would then show different behaviour. For reasons of simplicity, we did not add simulation results of a reference scenario without milk price disturbances to this chapter. Further developments of the model would include more possibilities for interaction between farm agents. If we would allow farm agents to transfer knowledge with each other, so that farmers can learn and adapt, the value of these indicators for operationalization of resilience would increase. Despite these limitations of the model, we conclude that this novel approach holds promise for the operationalization of resilience in rural areas.

7. Synthesis

7.1 Main findings

Resilience is an emerging concept in rural policy development and the term is also evident in scientific literature on the management of rural areas (FAO, 2012; Van Oudenhoven et al., 2011). Rural areas are increasingly changed by drivers on large spatial scales, such as globalization and climate change (Olesen and Bindi, 2002; Pedroli et al., 2007). These drivers bring forth abrupt disturbances, such as high output price peaks and falls, floods and droughts and massive outbreaks of animal diseases. Such disturbances cause a severe loss of e.g. welfare, culture and society, which negatively affects a rural areas' environmental and socio-economic development. The concept of resilience, which is defined as 'the capacity of a system to absorb disturbance, undergo change, and retain the same essential functions, structure, identity and feedbacks' (Holling, 1973; Carpenter et al., 2001), has been promoted as a guiding concept for the management of these areas (Wilson, 2010; Darnhofer et al., 2010; Van Apeldoorn et al., 2011; Cabell and Oelofse, 2012). In order to integrate resilience into rural management, I used an interdisciplinary approach focusing on rural areas as social-ecological systems (SESs), capturing their socio-economic (e.g. farm practices) and biophysical characteristics (e.g. landscape) (Berkes, 1998; Cumming, 2011). So far, resilience usually has been explored as a metaphorical or theoretical construct, as it is difficult to operationalize because of its abstract and multi-dimensional nature. However, to be able to use the concept in the management of rural SESs, it needs to be made operational and measurable (Cumming et al., 2005). With this thesis I contribute to scientific literature by operationalizing the concept of resilience for use as a management concept in rural SESs. To do so, first the concept of resilience was operationalized into measurable criteria that were considered as indicators for rural SESs resilience. And second, the behaviour of these indicators was assessed in an experimental setting capturing the complex dynamics of rural SESs by means of a <u>S</u>patially <u>E</u>xplicit <u>R</u>ural <u>A</u>gent-based model (SERA).

Agent-based modelling (ABM) approaches are increasingly popular as a method for the identification, development and evaluation of management interventions in complex resource management systems such as rural areas (see e.g. Happe et al., 2009; Lobianco and Esposti, 2010; Brady et al., 2012). However, when it comes to using ABM for the operationalization of resilience, only a few studies empirically operationalize the concept in their simulations, using system-specific definitions that are not all measurable (see Schlüter and Pahl-Wostl, 2007; Schlüter et al., 2009; Janssen and Carpenter, 1999; Leslie et al., 2009). With my approach I extended their work by including indicators that covered the interdisciplinary character of the rural SES, not limiting the scope to ecological indicators only. Next, the behaviour of the indicators during disturbances was assessed using SERA. The model builds on existing ABMs used to operationalize resilience by including a more realistic natural environment and capturing more social interactions between actors. Furthermore, the output of the model was validated in a sensitivity analysis comparing one-at-a-time and Monte Carlo approaches; this showed the added value of combined approaches for the understanding of nonlinearities and interactions in the model.

In turn, the measurable resilience criteria were applied to SERA and experiments were performed with different management strategies evaluating their contribution to enhancing the resilience of rural SESs. The following five research questions were addressed:

1. What constitutes resilience in rural social-ecological systems, and how can rural development policies be evaluated, based on criteria for building resilience?

2. How can the interdependence between socio-economic and biophysical components in rural SESs be explored across spatial and temporal scales by means of a spatially explicit agent-based model, and how does this inform governance processes for rural development?
3. How sensitive is the model to variations of parameters and inputs and how does this influence model outputs?
4. How can governmental incentives to foster rural landscape cohesion for biodiversity be made effective under fluctuating market conditions and thereby increase the landscapes ecological resilience?
5. What are the potentials and limitations of operationalizing resilience in rural social-ecological systems through measurable indicators, and how can this insight contribute to rural management and policy making?

This chapter reflects on these five research questions. They are addressed individually in the succeeding five subsections. Section 7.2 provides a reflection of the added value of the collection of chapters for rural policy makers and managers. Section 7.3 indicates directions for future research.

7.1.1 What constitutes resilience in rural social-ecological systems, and how can rural development policies be evaluated, based on criteria for building resilience?

What constitutes and enhances resilience has been the object of studies over the past decade, and the resilience of social, economic and natural resource management aspects within rural SES has also received attention (see e.g. Darnhofer, 2010; Van Apeldoorn et al., 2011). However, the impact of rural policies on the development of resilience in rural SESs has not yet been considered in literature. In Chapter 2 I attempted to fill this scientific gap by developing criteria for a policy objectives evaluation framework that analyses how rural development policies contribute to the resilience of rural areas. Given that no criteria concerning the development of resilience in rural SESs were available, I translated an existing list of criteria for resilience development in SESs by Walker and Salt (2006) into specifications for the rural case. Each criterion was described in its rural social-ecological context, and specifications were proposed that make each of the criteria applicable in judging and evaluating policy measures for developing resilience in rural SESs. The scope of the framework was limited to the evaluation of policy objectives, only considering the ex-ante evaluation of rural development policies. Ex-post evaluation fell outside the scope of the framework as this demands empirical data on the nature of disturbances, the way the policy was implemented, and an evaluation of the effectiveness of the policy.

The framework was applied to a case study, concerning the spending of 2009 Health Check compulsory modulation in the Netherlands. Strengths and weaknesses of the framework were signalled with respect to coherence and distinctiveness of the used criteria. Up till now, the criteria and specifications in the policy evaluation framework have been generic and abstract, with each criterion being given an equal weight. I viewed this as an advantage of the framework, as building resilience very much depends on the political, economic, ecological and social contexts of a case study. Therefore, this policy evaluation framework can serve as a starting point for socio-economic and ecological research and public debates about what aspects are critical for developing resilience in specific systems. To policy makers, the framework could indicate to what extent aspects of resilience are incorporated in rural policy plans, and may elucidate whether and how rural policies can contribute to the ability of rural SESs to respond to disturbances. In Chapter 6, the proposed criteria and rural specifications were used to measure resilience on a local rural level by means of measurable indicators.

7.1.2 How can the interdependence between socio-economic and biophysical components in rural SESs be explored across spatial and temporal scales by means of a spatially explicit agent-based model, and how does this inform governance processes for rural development?

In Chapter 3, SERA was developed to investigate the complex dynamics between rural actors, their social relationships and their dependency on the physical environment. Given the strengths and weaknesses of rural policies for enhancing resilience, as indicated in Chapter 2, SERA was developed to simulate how the contribution of these policies to resilience could be made effective while imposing disturbances to the system. Chapter 3 presented an extensive elaboration of the model. The aim of the model is to evaluate how rural policy interventions and socio-economic or ecological disturbances affect farmers, their land use and the landscape of which they are a part. SERA constitutes a virtual world of a rural region and comprises a large number of individually acting farms that operate with each other and with parts of their environment. The model initializes with empirical data on individual farms and existing agricultural spatial structures. Within the simulation, each farm agent is equipped with a behavioral model that guides decisions and keeps track of the agent's internal state described by attributes such as age, location and size. According to their behavioral model, the individual farm agents evolve subject to their state of attributes and to changes in their environment. Farm agents adjust their resource management (land, nature, livestock) in response to transactions on the land market, policy changes and changing market conditions. They adapt to these changing conditions by choosing alternative income strategies. In response to this changing farm agent behavior, changing land use patterns emerge.

SERA extends the work of other ABMs within the specific rural policy context, such as Berger (2001), Happe et al. (2009), Lobianco and Esposti (2010) and Schreinemachers and Berger (2011), in several respects. First, SERA combines spatially explicit landscapes with micro valuation of land through agents. Farm agents and their respective parcels are modeled in detail, including heterogeneity in parcel size, quality, shape and distance to the homestead. Second, farm agents interactions are included in SERA by means of a land auction mechanism that takes into account multiple parcels with multiple characteristics at once.

As such the model can be useful for policy makers to evaluate the impact of rural policies on the rural SES, by providing more insight into the system dynamics, and the role of individual decision-making for rural management. Although these insights provide potentially important information to policy makers on how to preserve rural areas, the model described in Chapter 3 is not yet ready to assess and operationalize resilience in rural SESs. In order to do this, indicators for resilience as well as disturbances have to be included in the model. In Chapters 5 and 6, these aspects were included, and experiments with different policy instruments were illustrated.

7.1.3 How sensitive is the spatially explicit rural agent-based model to variations of parameters and inputs, and how does this influence model outputs?

An important step in the validation of models that contain many parameters, such as SERA, concerns the treatment of the parameter set. Many agent-based modellers minimize model evaluation due to the absence of pre-existing work on standards for model validation (Verburg and Veldkamp, 2005). However, according to Gilbert (2008) sensitivity analysis is an essential element of the validation of ABMs, as more understanding is gained into the behaviour of the model. In Chapter 4 the sensitivity of SERA to changes in parameters that describe the farm agents, their land use and the landscape was analysed. In this way, it was discovered for which parameter changes the model's outputs were most sensitive. To analyse the sources of uncertainty in the model outputs, and to test the models degree of nonlinearity, I performed two sorts of sensitivity analyses. A mixed methodological approach was used, simulating the uncertainties one-at-a-time (OAT) (Saltelli et al., 2000), and then together in a Monte Carlo simulation using random sampling. The OAT sensitivity analysis consisted of varying selected parameters one after the other, while all other parameters are kept constant at their nominal value (also referred to as ceteris paribus approach). I selected this approach because it provides a rapid insight into the importance of parameters for the model output. Monte Carlo sensitivity analysis involves the variation of values for all selected input parameters simultaneously using Monte Carlo sampling from pre-defined probability distribution functions (Hamby, 1994; Saltelli et al., 2000). The Monte Carlo approach confirmed the OAT simulation results and gave further insight into the nonlinear relations between parameters and outputs. Furthermore, the use of meta-modelling and Bottom and Top Marginal Variances (Jansen et al., 1994) provided insights into the interactions between parameters and whether they inhabit conditional terms.

My conclusion was that applying a combined approach to the sensitivity analysis of an ABM provided a better understanding of the model's behaviour by revealing non-linear relations between parameters and outputs, interactions between parameters and possible conditional terms. Based on these insights, the parameters that mostly affected the outputs were critically reviewed, and their estimates were brought in accordance to scientific literature and information from the case study, so that reliable results were ensured. The reliability of the results turned out to be important in Chapters 5 and 6, where SERA was used for the operationalization of resilience in rural SESs, and experiments were conducted with different policy instruments. In these chapters, the behavior of the resilience indicators was strongly influenced by the assumptions built into the model.

7.1.4 How can governmental incentives to foster rural landscape cohesion for biodiversity be made effective under fluctuating market conditions and thereby increase the landscapes ecological resilience?

Chapter 5 discussed the implementation of SERA for assessing ecological resilience under different policy scenarios in the case study area Winterswijk. SERA was used to explore how farmers' decisions to include biodiversity conservation in their enterprise are affected by fluctuating market conditions (volatile milk prices), and how they respond to different instruments of agri-environment schemes (AESs). Within the EU Common Agricultural Policy (CAP), AESs are an example of how governments provide incentives to stimulate farmers to preserve biodiversity. However, the effectiveness of these incentives in raising biodiversity levels is questioned. Baylis et al. (2008) and

Whittingham (2011) suggested both ecological and governance-related reasons for this lack of effectiveness. One of the reasons is that AESs payments are paid irrespective of the ecological and spatial context of the parcels, and therefore there is no incentive for farmers to contract AESs on parcels with potentially high contribution to biodiversity conservation.

Two different AESs payment scenarios were considered: a scenario in which a fixed annual compensatory payment per hectare was given, irrespective of the location and spatial configuration of the parcel in the landscape, and a scenario in which flexible payments were given, depending on the contribution of parcels to habitat networks. The dynamic relationship between volatile milk prices, intensity of farming and local conditions for biodiversity were addressed in the context of resilience thinking. For reasons of feasibility, only ecological resilience was analysed, by measuring the uptake of AESs given the two payment scenarios and analysing their contribution to the connectivity of the parcels within habitat networks. The more species populations can survive disturbances, the higher the ecological resilience of the system (Hanski, 1999). In this case, the cohesion of the conservation network was augmented by adding a piece of AESs' land to the network as a proxy for improved spatial conditions for biodiversity (Opdam et al., 2008).

Results showed that during periods of big price falls, farmers have the tendency to switch to contracting AESs as they try to secure their income. When a flexible compensatory payment was given, based on the contribution of the parcel to habitat networks, farmers were observed to be more willing to contract parcels that were close to nature conservation areas, because of higher payments given. It was concluded that parcel size, parcel quality as well as distance to the homestead are decisive characteristics for farmers in their decision making process to contract parcels with AESs. Small parcels with low quality that are situated further away from the farmstead were offered for AESs at a higher pace, compared to high quality large parcels located near the farmstead. When imposing milk price disturbances to the system, the fixed compensatory payment scenario turned out to be more sensitive to fluctuations in milk prices than the flexible compensatory payment scenario. In years of low milk price, farmers preferred to contract AESs because of the higher revenue that was gained as they try to attain the highest possible income from their land. During high price years, farmers decided to focus on food production instead of biodiversity conservation.

The results showed that when rural policy makers try to achieve the highest amount of AESs hectares, independent of the contribution to spatial cohesion of individual parcels, a fixed compensatory payment is preferable. However, the case study showed that when policy makers try to enhance ecological resilience by aiming at the highest contribution to the spatial habitat network, spatially dependent payments were shown to be the most effective. These conclusions are of relevance to discussions between policy makers, managers and scientists on which aspects of the system are critical for developing ecological resilience. Furthermore, the experiences gained with respect to operationalization of ecological resilience were used to develop measurable indicators for assessing rural SES resilience in Chapter 6.

7.1.5 What are the potentials and limitations of operationalizing resilience in rural social-ecological systems through measurable indicators, and how can this insight contribute to rural management and policy making?

As indicated in the introduction of this chapter, Cumming et al. (2005) stated that in order to use the concept of resilience in the management of rural areas, it needs to be made operational and measurable. However, its abstract and multidimensional nature makes resilience difficult to measure, and therefore Carpenter et al. (2001), Bennett et al. (2005), and Cumming et al. (2005) propose monitoring measurable criteria that can be considered as indicators for the resilience of the SES. In Chapter 6, this approach is applied to the rural SES by using a list of criteria for resilience that was used in Chapter 2 for the development of the rural policy evaluation framework. Taking these criteria as a starting point, Chapter 6 explored the potentials and limitations of operationalizing resilience in rural SESs through measurable indicators. The way these indicators behave in a rural SES in times of disturbances was tested using SERA.

The approach was illustrated by comparing two management regimes (namely i) a self-governance and ii) a hierarchical governance regime) in two experiments aiming at conserving farmland biodiversity in the case study area Winterswijk. In the context of hierarchical governance, the main actors were governments, while in the context of self-governance the central role was played by organizations of collective interests. I focused on a special form of self-regulation: the environmental cooperative, which is a regional organization in which farmers collaborate to integrate environmental values into their production process (Polman and Slangen, 2008). Lebel (2006) hypothesized that moving away from the traditional way of steering rural policies towards self-governance, in which the main actors are organizations with collective interests, can make the system more flexible and adaptive to disturbances and thus enhance resilience. The two conducted experiments were a voluntary AESs measure, which was applied earlier in Chapter 5, and the compulsory 7% Ecological Focus Areas (EFAs) measure which is part of the European Commission proposals for the CAP 2014-2020 (EC, 2011). The 7% EFA measure obliges farmers to convert 7% of their agricultural land for biodiversity purposes, designed to preserve ecological reserves and landscapes.

In translating the resilience criteria into measurable indicators I encountered model limitations and restrictions in quantifying some criteria. Therefore, I selected two resilience criteria that Walker and Salt (2006) introduced: ‘diversity’, which encompasses biological diversity, diversity of income sources and farm diversity, and ‘social capital’, which was interpreted as the existence of networks between rural actors. Furthermore, average farm income was added as an extra indicator, omitted by Walker and Salt (2006). The simulation results showed that the behaviour of the resilience indicators was strongly influenced by the characteristics of the case study area, and the assumptions built into the model. For the latter a sensitivity analysis was conducted, which was discussed in Chapter 4. Results of the sensitivity analysis showed that the behaviour of the resilience indicators in response to milk price disturbances was strongly influenced by the large number of interactions between parameters, and inhabited conditional terms.

The approach used in Chapter 6 was compared to other ABM approaches focusing on assessing resilience in SESs such as Schlüter and Pahl-Wostl (2007), Schlüter et al. (2009) and Leslie et al. (2009). My approach built on existing literature by including more detailed ecosystem and socio-economic system characteristics. The ecosystem component included more detailed maps on current land use, soil quality and crop suitability. The socio-economic component included farm agents that were more heterogeneous with respect to their farm characteristics: e.g. age, farm size, livestock, availability of a successor, and that were able to participate in social networks. Furthermore, the approach in Chapter 6 built on these other approaches as I not only focussed on ecological indicators for resilience, but also captured social and economic components of the rural SESs by including indicators on farm size, farm income, diversification, spatial configurations and social interactions. Rural policy makers and managers can use the results of SERA and the proposed resilience indicators to evaluate to what extent management strategies contribute to resilience in rural SESs. Where Chapter 5 focused on the operationalization of one ecological indicator for resilience (biodiversity conservation), Chapter 6 extended the number of measurable indicators aiming at capturing the biophysical and socio-economic characteristics of the rural SES. In this way, more insight was gained into the behaviour of the rural SES in response to disturbances, which is useful for policy makers when evaluating the impact of alternative management strategies.

7.2 Application

Given the main findings discussed in Section 7.1, this section further elaborates on the societal contribution of the work presented in this thesis.

Accepting sustainable development of rural areas as a main framework for decision-making in the EU, this thesis provides arguments for explicitly acknowledging resilience in the policy making process. My results suggest that if rural policies would allow rural communities to adapt policy goals to the local context, this will enhance the resilience of the social-ecological system and thereby increase its capacity to provide the goods and services as disturbances occur. These 'tailor-made' policies would leave room for implementation that adjusts to local demands. This is in line with Persha et al. (2011) and Reed (2008), who conclude that stakeholder participation in local decision making contributes to sustainable development. Policies that do not allow for this local implementation would result in homogenization of provided rural goods and services at local level, which in turn leads to a decrease in resilience. As indicated in Chapter 6, collective initiatives, such as environmental cooperatives, could assist in adjusting policies to local demands, given their local expertise.

The resilience criteria proposed in this thesis can provide a starting point for discussion among policy makers, managers, scientists and rural stakeholders about which aspects of the system are of vital importance for the survivability of rural SESs in times of disturbances, and that need policy support. SERA can subsequently serve as a useful tool to explore the contribution of potential rural policy scenarios to the resilience of the rural SES, while disturbances are imposed. By monitoring the proposed resilience indicators in the model, covering both the biophysical and socio-economic characteristics of the rural SESs, rural policy makers and managers get more insight into the supposedly vulnerable parts of the system. These monitoring data can also be used to evaluate how policies have contributed to enhanced resilience. Furthermore, as Chapter 6 illustrates, the model can also be used to explore the impact of different rules and incentives on the behaviour of local rural SES. These insights may be valuable to answer questions about conditions that stimulate the self-governing capacity of actors through local organizations and collective interests to create sustainable rural development (Glasbergen, 2000). The impact of different types of management regimes on rural SESs was earlier illustrated in a project commissioned by the PBL Netherlands Environmental Assessment Agency in 2012 (Schouten et al., 2013b). In this project, the practical use of SERA for rural policy making was illustrated by assessing the potential contribution of environmental cooperatives in executing the proposals for the new CAP 2014-2020 towards developing farmland biodiversity. Moreover, Chapter 5 illustrated that the tool also gives insight into the most effective allocation of budgets for agri-environmental nature conservation. The results suggested that a potential win-win situation was created, leading to an increase in biodiversity development against lowest costs.

7.3 Directions for future research

This thesis proposes an approach to operationalize the concept of resilience for the management of rural SESs. However, many research challenges remain. For this thesis, I distinguished criteria for resilience in rural SESs based on a list provided by Walker and Salt (2006). I used this list because of its explicit link with SESs, and because at the time of writing this thesis it was the only list available that covers a large number of aspects of the SES. However, using this list for evaluating how rural policies contribute to rural resilience has its limits. This thesis showed that not all criteria were appropriate for evaluating resilience, both in the policy evaluation framework and at rural SES level. Contradictions and overlap between the criteria were detected, and some were not easy to monitor because they were not scaled to a time or spatial dimension. Because of these shortcomings, only two resilience criteria were operationalized into measurable indicators. In order to get a more comprehensive and measurable set of criteria, interdisciplinary research is needed that critically reviews the existing criteria, improves them, and develops new criteria.

When evaluating the informative use of the resilience indicators, I concluded that this thesis extends to existing literature by not only incorporating ecological resilience indicators, but also adding socio-economic resilience indicators. Where ecological and economic resilience indicators can be underpinned with historical datasets, population dynamics models, or economic theory, social resilience indicators are often lacking because of limited data availability. In this thesis, the social indicators were also underrepresented, as social networks only were incorporated in the model by looking at the exchange of greening permits. By working closely together with social scientists, conducting more experiments on social networks and the importance of working together in environmental cooperatives, more insights can be gained into the importance of social aspects of the system for resilience, which will also improve the social resilience indicators.

Giving insight into the dynamics of the rural SES by means of SERA turned out to be a useful tool to evaluate rural policies on their contribution to developing resilience, and to gain insight into the adaptive strategies of farmers against disturbances. The model was shown to contribute to scientific literature by combining economic and environmental heterogeneity among agents, capturing interactions between agents and facilitating the combination with spatial modules simulating environmental dynamics. Future developments of the model are desirable with respect to the ecological-, and socio-economic characteristics of the model. With respect to the ecological characteristics, a valuable improvement would be to integrate species population dynamics into the model. Up till now, the model only focused on spatial habitat networks in the rural SESs. By adding information on the dynamics of species populations, the ecological resilience indicators used in

Chapter 6 will be more informative. With respect to the socio-economic characteristics of the model, its informative use can be improved by adding public and private transactions costs to the farm agent decision-making in the model, and by including more possibilities for farm agents to interact in social networks, learn from each other and adapt. Furthermore, a sensitivity analysis for the 7% EFAs measure, discussed in Chapter 6, has not yet been carried out and is part of future work.

These research challenges will contribute to a more operational definition of resilience, and will increase its practical use in policy development. In order to make sure that rural policy makers and managers actually integrate aspects of resilience into the policy-making process, the practical use of SERA and the resilience indicators developed in this thesis need to be illustrated by conducting more experiments with e.g. the new proposals for the EU CAP. Resilience remains a normative concept in which rural stakeholders, managers and policy makers decide on what is resilient to what (Carpenter et al., 2001). The approach used in this thesis thereby serves as a first step to getting closer to the practical implementation of the concept. However, to make sure that resilience does not end up as nothing more than a temporary hype that slowly fades into the background, an interdisciplinary approach is needed in which ecologists, economists and researchers from other disciplines must take up the challenge to provide further insight into the fundamental economic, ecological and social dimensions of resilience. Getting the right models, theories and practical examples will be the key to a successful identification of resilience.

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Summary

Rural areas are increasingly changed by drivers on large spatial scales such as economic globalization and climate change. These international drivers may bring forth abrupt disturbances, such as high output price peaks and falls, water floods and droughts, and massive outbreaks of animal diseases (BSE, avian influenza) which negatively affect a rural areas' environmental and socio-economic development. To understand such effects, approaches are needed that consider rural areas from a complex system perspective, taking into account the interdependence between ecological and socio-economic dynamics.

Therefore, in this thesis I consider rural areas as a social-ecological system (SES), characterized by strong links between the social and the ecological component, and by multiple interactions across spatial and temporal scales. The behaviour of such a complex system is highly unpredictable, and the effects of disturbances therefore highly uncertain. In this context, resilience has been promoted as a concept to guide and direct the management of SESs. Stemming from ecology, the concept became incorporated into various other scientific disciplines such as psychology, political science and economics. Resilience is a system property that reflects the capacity of a system to absorb disturbance, undergo change, and retain the same essential functions, structure, identity and feedbacks.

So far, resilience has often been explored as a metaphorical or theoretical construct. A reason for this may be that (i) different fields use the term to mean slightly different things (compare, for example, psychological resilience and ecological resilience); and (ii) it is difficult to operationalize because of its abstract and multi-dimensional nature. However, to be able to use the concept in the management of rural SESs, it needs to be made operational and measurable. The objective of this thesis is to explore how the concept of resilience can be operationalized and implemented into the management of rural social-ecological systems. This general objective can be divided into two sub goals. The first objective aims to identify criteria that can be considered as indicators for a rural SESs resilience. The second objective aims at assessing the behaviour of these indicators in an experimental setting, capturing the complex dynamics of rural SESs by means of a spatially explicit agent-based model. By this I attempt to provide management advice that takes the coevolving nature of rural SESs into account and supports strategies to cope with uncertainty. This general research objective has been covered in Chapter 2-6.

The objective of Chapter 2 is to develop criteria for a policy objectives evaluation framework that analyses how rural development policies contribute to the resilience of rural areas. Each criterion is described in its rural social-ecological context and specifications are proposed that make each of the criteria applicable in judging and evaluating policy measures for developing resilience in rural SESs. The scope of the framework is limited to the evaluation of policy objectives, only considering the ex-ante evaluation of rural development policies. The framework is applied to European rural

development policies, specifically focusing on the spending of compulsory modulation budget. The case study signalled the strengths and weaknesses of the framework with respect to the coherence and distinctiveness of the used criteria.

In Chapter 3 a spatially explicit rural agent-based model (named SERA) is developed which aims at evaluating how rural policy interventions affect farmers, their land use and the landscape of which they are a part. Using the criteria proposed in Chapter 2, the model provides a way to evaluate how the contribution of these policies to resilience could be made effective, while imposing disturbances to the system. The model constitutes a virtual rural region, comprised by a large number of individually acting farms that operate with each other and with parts of their environment. The model initializes with empirical data on individual farms and existing agricultural spatial structures. According to their behavioural model, the individual farm agents evolve subject to their state of attributes and to changes in their environment. Farm agents adjust their resource management (land, nature, livestock) in response to transactions on the land market, policy changes and changing market conditions. They adapt to these changing conditions by choosing alternative income strategies. In response to their changed behaviour, land use patterns change.

Chapter 4 investigates the sensitivity of the model output to changes in parameters. In this way, the parameters that are the key drivers of the model results were discovered. A mixed methodological approach was used, simulating uncertainties one-at-a-time and then together in a Monte Carlo simulation using random sampling. This mixed methodological approach provides understanding in the model's behaviour by revealing non-linear relations between parameters and outputs, interactions between parameters and possible conditional terms.

Chapter 5 discusses the implementation of the model for assessing ecological resilience under different policy scenarios in the case study area Winterswijk. The model SERA is used to explore how farmers decisions to include biodiversity conservation in their enterprise are affected by fluctuating market conditions, and how they respond to two different policy scenarios aiming at biodiversity conservation. The first policy scenario includes a fixed compensatory payment per hectare, irrespective of the location and spatial configuration of the parcel in the landscape. In the second policy scenario spatially dependent payments are given, depending on the contribution of parcels to species habitat networks. Results show that during periods of large price falls, farmers have the tendency to switch to biodiversity conservation contracts as they try to secure their income. Parcel size, quality and distance to the homestead show to be decisive characteristics in the decision making process. Furthermore, it is shown that whenever policy makers aim at achieving the highest amount of contracted hectares, a fixed payment is preferable. Whenever they aim at the highest contribution to ecological resilience, they should switch to spatially dependent payments.

Chapter 6 explores potentials and limitations of operationalizing resilience in rural SESs through measurable indicators. The resilience criteria proposed in Chapter 2 are translated into measurable indicators and their behaviour in a rural SES in times of disturbances is tested using the agent-based model discussed in Chapter 3. The approach is illustrated by comparing two management regimes, namely self-governance and hierarchical governance, in two experiments aiming at conserving biodiversity in the case study area Winterswijk. The first experiment focuses on agri-environment schemes, compensating farmers to preserve biodiversity. The second experiment concerns the compulsory 7% Ecological Focus Areas measure, which is part of the European Commission proposals for the Common Agricultural Policy for the 2014-2020 period. Difficulties were encountered when translating the resilience criteria into measurable indicators due to model limitations and restrictions in quantifying some criteria. Therefore, three resilience criteria were selected and operationalized into seven measurable indicators. Results show that some indicators are more informative than others, which is caused by a strong influence of the characteristics of the case study area, and of the assumptions built into the model. Furthermore, the self-governance regime shows the largest contribution to enhancing resilience in rural SESs. The model and the proposed resilience indicators can assist rural policy makers to evaluate to what extend management strategies contribute to resilience in rural SESs.

Chapter 7 provides a discussion of the findings from Chapter 2-6 and provides a reflection of the scientific added value of the collection of chapters and what their main messages are to the rural policy makers and managers. This thesis contributes to scientific literature by operationalizing the concept of resilience for use as a management concept in rural SESs. Only few studies empirically operationalize resilience in agent-based simulations, and this approach builds on existing literature by including indicators that covered the interdisciplinary character of the rural SES, not limiting the scope to ecological indicators only. The spatially explicit agent-based model builds on existing ABMs used to operationalize resilience by emphasizing more on the economic, ecological and social dimensions of rural SESs, including a more realistic natural environment and capturing more social interactions between actors. Furthermore, the output of the model was validated in a sensitivity analysis comparing one-at-a-time and Monte Carlo approaches; this showed the added value of combined approaches for the understanding of nonlinearities and interactions in the model.

To rural policy makers and managers, this thesis provides arguments for acknowledging resilience in the policy making process, while accepting sustainable development of rural areas as a main framework for decision-making in the EU. The resilience criteria proposed in this thesis can provide a starting point for discussion among policy makers, managers, scientists and rural stakeholders about which aspects of the system are of vital importance for the survivability of rural SESs in times of disturbances, and need policy support. The spatially explicit agent-based model can subsequently serve as a useful tool to explore the contribution of potential rural policy scenarios to the resilience of the rural SES, while disturbances are imposed.

Samenvatting

Het landelijk gebied wordt in toenemende mate beïnvloed door ingrijpende veranderingen op mondiale schaal, zoals globalisering en klimaatsverandering. Deze mondiale veranderingen kunnen abrupte, kortdurende verstoringen veroorzaken. Hierbij kan worden gedacht aan prijsschokken, overstromingen, droogtes en uitbraken van dierziektes (zoals BSE en vogelgriep). Deze abrupte verstoringen kunnen een negatieve invloed hebben op de sociaal-economische en ecologische ontwikkelingen van het landelijk gebied.

Om inzicht te krijgen in de impact van deze verstoringen op het landelijk gebied zijn benaderingen nodig die kijken naar het landelijk gebied als een complex systeem, waarbij interacties en terugkoppelingen tussen de sociaal-economische (mens) en ecologische (natuur) dimensies van het systeem worden meegenomen. Daarom wordt in dit proefschrift het landelijk gebied gezien als een sociaal-ecologisch systeem (SES). Een SES wordt gekenmerkt door afhankelijkheid tussen sociaal-economische en ecologische componenten, waarbij interactie tussen de componenten kan plaatsvinden door zowel tijd als ruimte. Het gedrag van een SES is complex en onvoorspelbaar, en de invloed van verstoringen op het systeem is dan ook onzeker. Veerkracht wordt vaak geïntroduceerd als concept voor het beheer van een dergelijk complex systeem in tijden van onzekerheid. Het concept vindt zijn oorsprong in de ecologie, om later ook te worden toegepast in andere wetenschappelijke disciplines zoals psychologie, politicologie en economie. Veerkracht wordt gedefinieerd als een eigenschap van het SES dat weergeeft hoeveel verstoringen een systeem kan absorberen en hoeveel veranderingen het kan ondergaan, zonder dat essentiële functies, structuur en identiteit verloren gaan.

Tot op heden wordt veerkracht vaak gebruikt als metafoor, of als onderdeel van een theoretisch raamwerk. Belangrijkste reden voor deze vooral theoretische toepassingen is dat er i) door verschillende disciplines verschillende interpretaties worden gegeven aan het concept, en ii) veerkracht moeilijk meetbaar is door het abstracte en multidisciplinaire karakter. Juist het kunnen meten en operationaliseren van veerkracht is van belang om het concept te kunnen toepassen in het beheer van het landelijk gebied. Het doel van dit proefschrift is dan ook om na te gaan hoe veerkracht meetbaar en operationaliseerbaar kan worden gemaakt, om vervolgens toegepast te worden in beleid voor het beheer van rurale SES. Dit hoofddoel bestaat uit twee subdoelen. Het eerste subdoel is om criteria te onderscheiden die kunnen fungeren als indicatoren om veerkracht in een systeem te analyseren. Het tweede subdoel is om het gedrag van deze indicatoren in een experimentele setting te analyseren, waarbij de complexiteit van de SES wordt gevat in een ruimtelijk expliciet agent-gebaseerd model. Met behulp van dit model probeer ik inzicht te geven in de invloed van verstoringen op de dynamiek van het landelijk gebied, om vervolgens te analyseren hoe beleidsinstrumenten ondersteuning kunnen bieden voor behoud van de functies, structuur en identiteit van het landelijk gebied. Deze doelen worden behandeld in de hoofdstukken 2 tot en met 6.

Het doel van hoofdstuk 2 is om criteria te ontwikkelen voor een ex-ante beleidsevaluatie raamwerk dat nagaat in hoeverre beleidsinstrumenten bijdragen aan de ontwikkeling van veerkracht in het landelijk gebied. Allereerst wordt ieder criterium besproken in zijn ruraal sociaal-ecologische context. Vervolgens worden deze criteria gespecificeerd zodat ze bruikbaar zijn voor de evaluatie van beleidsinstrumenten op basis van hun bijdrage aan de ontwikkeling van veerkracht in rurale SES. Het raamwerk richt zich specifiek op de evaluatie van ex-ante beleidsdoelen. Daarna wordt deze methode toegepast op een case studie over beleidsinstrumenten voor Europese plattelandsontwikkeling, specifiek gericht op besteding van gelden die zijn vrij gekomen door afroming van inkomenssteun ten behoeve van plattelandsontwikkeling (modulatie). Deze case studie toont de sterke en zwakke punten van het raamwerk met betrekking tot samenhang en onderscheidend vermogen van de ontwikkelde criteria.

In hoofdstuk 3 wordt het ruimtelijk expliciete model gebaseerd op beslissingen van individuele landeigenaren (boeren) (afkorting 'SERA') ontwikkeld. Dit model evalueert de invloed van beleidsinstrumenten op boeren, hun landgebruik, en het omringende landschap. Het model biedt de mogelijkheid om in een experimentele setting verstoringen toe te dienen aan het systeem. De criteria ontwikkeld in hoofdstuk 2 geven in dit hoofdstuk inzicht in de invloed van beleidsinstrumenten op de ontwikkeling van veerkracht. Het model vertegenwoordigt een ruraal SES op regioniveau, met daarin een groot aantal boeren die interacteren met elkaar en met hun omgeving. Het model is gebaseerd op empirische data van individuele bedrijven en informatie over landgebruik en landschapselementen. De individuele boeren worden door middel van gedragsregels gemodelleerd als agenten in SERA, die de mogelijkheid hebben om zich door de tijd heen te ontwikkelen en aan te passen als gevolg van veranderingen in hun persoonlijke situatie en bedrijfsvoering, en veranderingen in beleid en omgeving. De agenten kunnen zich aanpassen door het landgebruik op hun percelen te veranderen, of percelen te verhandelen op een landmarkt. Veranderingen in het gedrag van de agent zorgen zo voor veranderingen in het landschap.

In hoofdstuk 4 wordt inzicht verkregen in de invloed van elk van de parameters op het model en de resultaten. Een gevoeligheidsanalyse wordt uitgevoerd door twee verschillende technieken toe te passen: een *'one-at-a-time'* benadering, waarbij de afhankelijkheid voor specifieke parameters één voor één wordt bekeken, en een *'Monte Carlo'* benadering, waarbij alle parameters op hetzelfde moment worden gevarieerd door middel van *random sampling*. Door verschillende technieken toe te passen wordt meer inzicht verkregen in niet-lineaire relaties in het model, mogelijke interactietermen en conditionele termen.

In hoofdstuk 5 wordt het model toegepast op de regio Winterswijk, en wordt gekeken hoe de ecologische veerkracht van het gebied onder verschillende beleidsscenario's verandert ten tijden van schokken. Specifiek wordt gekeken naar de invloed van fluctuerende marktprijzen op de bereidheid van boeren om agrarisch natuurbeheer uit te voeren op hun bedrijf. Inzicht wordt verkregen in de reactie van boeren op deze prijsschokken, en in welke mate twee alternatieve beleidsscenario's bijdragen aan het behoud van biodiversiteit. In het eerste beleidsscenario wordt het huidige beleid ten aanzien van agrarisch natuurbeheer in Nederland gesimuleerd, waarbij een vaste vergoeding per hectare wordt verstrekt die onafhankelijk is van de locatie en ligging van het perceel in het landschap. In het tweede beleidsscenario worden vergoedingen verstrekt die afhankelijk zijn van de bijdrage van het perceel aan het ecologisch netwerk in het gebied. De resultaten laten zien dat gedurende grote dalingen in marktprijzen boeren sneller geneigd zijn om contracten voor agrarisch natuurbeheer af te sluiten. Deze contracten vormen een alternatieve inkomensbron, met als doel het inkomen van de boeren veilig te stellen. Oppervlakte van het perceel, bodemkwaliteit en afstand tot de huiskavel spelen een grote rol in de besluitvorming van de boer. Verder laten de resultaten zien dat wanneer beleidsmakers gericht zijn op een zo groot mogelijke gecontracteerde oppervlakte, een vaste betaling per hectare het meest effectief is. Wanneer zij tot doel hebben een zo groot mogelijke bijdrage aan de ontwikkeling van biodiversiteit te realiseren, blijkt een betaling op basis van de bijdrage van het perceel aan het ecologisch netwerk het meest effectief. Deze betaling draagt op zijn beurt het meeste bij aan de ecologische veerkracht van het gebied.

In hoofdstuk 6 worden de mogelijkheden en beperkingen verkend van het operationaliseren van veerkracht in rurale SES door middel van meetbare indicatoren. De in hoofdstuk 2 ontwikkelde veerkrachtcriteria worden vertaald naar meetbare indicatoren. Vervolgens wordt de manier waarop de indicatoren zich gedragen ten tijden van schokken geanalyseerd door middel van het in hoofdstuk 3 ontwikkelde agent-gebaseerde model. Twee verschillende sturingsmechanismen voor het beheer van het landelijk gebied worden hier vergeleken: zelfsturing door collectieven en *top-down*-sturing door de overheid. Deze twee mechanismen worden toegepast in twee experimenten gericht op behoud en ontwikkeling van biodiversiteit in de regio Winterswijk. Het eerste experiment richt zich op agrarisch natuurbeheer, het tweede experiment richt zich op ecologische aandachtsgebieden. Ecologische aandachtsgebieden zijn onderdeel van een voorstel van de Europese Commissie voor het Gemeenschappelijk Landbouwbeleid voor de periode 2014-2020, waarbij boeren worden verplicht om 7% van hun agrarisch land om te zetten voor ecologische doeleinden.

Het operationaliseren van de veerkrachtcriteria wordt bemoeilijkt doordat niet alle criteria te kwantificeren zijn, en door de beperkingen van het model. Daarom zijn uiteindelijk drie criteria geselecteerd, die vervolgens zijn vertaald in zeven meetbare indicatoren. Resultaten laten zien dat sommige indicatoren sterk worden beïnvloed door eigenschappen van het case studie gebied, en door aannames in het model. Verder laten de resultaten zien dat zelfsturing zorgt voor de grootste bijdrage aan veerkracht in een ruraal SES. Het model en de voorgestelde veerkrachtindicatoren kunnen beleidsmakers helpen bij het evalueren van de invloed van sturingsmechanismen op de ontwikkeling van veerkracht in een ruraal SES.

Hoofdstuk 7 is een synthese van de belangrijkste conclusies uit hoofdstukken 2 tot en met 6 en bespreekt de toegevoegde wetenschappelijke waarde van de hoofdstukken, en de toegevoegde waarde voor beleidsmakers en gebiedscoördinatoren. Dit proefschrift draagt bij aan actuele wetenschappelijke discussies over het operationaliseren van het concept veerkracht, en het gebruik van het concept voor het beheer van het landelijk gebied. Slechts een aantal studies zijn bekend die veerkracht operationaliseren in empirische case studies door middel van agent-gebaseerde simulaties. De benadering in dit proefschrift bouwt hierop voort door zich niet alleen te richten op ecologische indicatoren voor veerkracht, maar door indicatoren te ontwikkelen die het interdisciplinaire karakter van het rurale SES proberen te omvatten. Verder bouwt SERA voort op bestaande agent-gebaseerde benaderingen door meer nadruk te leggen op de interacties en terugkoppelingen tussen economische, ecologische en sociale componenten van het rurale SES, door meer landschapsdetails weer te geven, en door sociale netwerken tussen agenten te integreren in het model. Tot slot is de benadering om inzicht te krijgen in de gevoeligheid van het model vernieuwend, doordat verschillende technieken zijn toegepast om meer inzicht te krijgen in niet-lineariteit, interactietermen en conditionele termen van het model.

Gezien het belang van duurzame ontwikkeling van het landelijk gebied in besluitvorming in de EU, geeft dit proefschrift argumenten voor integratie van het concept veerkracht in beleidsvorming. De veerkrachtscriteria die zijn ontwikkeld in dit proefschrift kunnen een uitgangspunt vormen voor discussies tussen beleidsmakers, gebiedscoördinatoren, rurale actoren en wetenschappers over welke aspecten van het systeem van essentieel belang zijn voor duurzame ontwikkeling van rurale SES ten tijden van schokken en hoe beleid hierin een ondersteunende rol kan vervullen. Het ruimtelijk expliciete agent-gebaseerde model kan op zijn beurt verder inzicht verschaffen in de bijdrage van potentiële rurale beleidsinstrumenten aan veerkracht in een ruraal SES, door te experimenteren met verschillende beleidsscenario’s ten tijden van schokken.

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Marleen
Oosterblokker, May 2013

About the author

Curriculum vitae

Maria Agnes Helena (Marleen) Schouten was born on December 30, 1983 in Hoorn, The Netherlands. In 2002 she finished secondary school (Atheneum) at the Oscar Romero in Hoorn. The same year, she started a study Management and Economics at Wageningen University. In 2006 she also started a Master Food and Resource Economics at the Rheinische Friedrich-Wilhelms Universität in Bonn, Germany. In 2008 she graduated from both masters, within the specialization Regional Economics and Agricultural Economics.

After graduation, Marleen worked as a research scientist at the Agricultural Economics Research Institute (LEI) in The Hague for a few months. In May 2008 Marleen started as a PhD student at Wageningen University. At first, situated at the Economics of Consumers and Households group, and later as part of the Agricultural Economics and Rural Policy group. During this period, Marleen visited the group of Marco Janssen and Elinor Ostrom at Arizona State University in Phoenix, Arizona (USA) as a guest scholar. Her research on resilience in rural social-ecological systems has been presented at international conferences and is published in peer reviewed journals. Besides that, she contributed with a paper on agent-based modelling and agri-environment schemes to the 2012 OECD proceedings ‘Evaluation of Agri-Environmental Policies: Selected Methodological Issues and Case Studies’. In the same year, Marleen acted as a project leader in the project ‘Greening under the new European Common Agricultural Policy: exploring cooperative approaches with a spatially explicit agent-based model’, commissioned by PBL Netherlands Environmental Assessment Agency and the Dutch Ministry of Economic Affairs.

Since December 2012 Marleen is employed as a postdoctoral researcher at the Institute for Environmental Studies (IVM), Department of Spatial Analysis and Decision Support of the VU University Amsterdam.

Maria Agnes Helena Schouten
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Name of the course	Department/ Institute	Year	ECTS[1]
General part			
PhD Competence Assessment	WGS[2]	2008	0.3
Techniques for writing and presenting scientific papers	WGS	2008	1.2
Effective behaviour in your professional surroundings	WGS	2008	0.5
II. Mansholt-specific part			
Mansholt Introduction course	WASS[3]	2008	1,5
'Resilience of social-ecological systems in European rural areas: theory and prospects'	WASS PhD Day	2009	1
'Less favoured area measure in the Netherlands: a welcome or negligible addition?'	12th EAAE Congress, Ghent, Belgium	2008	1
'Resilience of social-ecological systems in European rural areas: theory and prospects'	113th EAAE Seminar, Belgrade, Serbia	2009	1
'Assessing the resilience of rural common-pool resources using multi-agent simulation'	IASC, Tempe, AZ, USA	2010	1
'Landscape cohesion and the conservation potential of landscapes for biodiversity: evaluating agri-environment schemes using a spatially explicit agent-based modelling approach'	OECD[4] Workshop, Braunschweig, Germany	2011	1
'Rural Landscapes in Turbulent Times: A Spatially Explicit Agent-Based Model for Assessing the Impact of Agricultural Policies'	8th Artificial Economics Conference, Castellón, Spain	2012	1
III. Discipline-specific part			
Advanced Econometrics (AEP 60306)	Wageningen University	2009	6
Qualitative Data Analysis: procedures and strategies (YRM 60806)	Wageningen University	2008	6
Spatial planning and design of climate-change-proof ecosystem networks (LUP 90806)	Wageningen University	2009	6
Summer School 2009 Understanding Global Environmental Change, Amsterdam	SENSE	2009	3
Marie Curie PhD Winter School on Adaptive Governance	IVM[5]	2009	3
PhD Workshop (Rotterdam) Multi Agent Systems Research	ERIM[6]	2009	5
Land Use Modelling with Metronamica (Maastricht)	RIKS[7]	2010	1
IV. Teaching and supervising activities			
2009 Summer School Rural Development (organization and assistance at lectures)	Wageningen University	2009	4
		TOTAL	43 .5

[1] 1 ECTS (European Credit Transfer System) represents 28 hours.
[2] WGS stands for Wageningen Graduate Schools.
[3] WASS stands for Wageningen School of Social Sciences.
[4] OECD stands for Organisation for Economic Co-operation and Development.
[5] IVM stands for Institute for Environmental Studies.
[6] ERIM stands for Erasmus Research Institute of Management.
[7] RIKS stands for Research Institute for Knowledge Systems.