Strategies for our changing and complex world:

concepts, methods and applications

Complex Adaptive Systems

WAGENINGEN UR
For quality of life

Table of contents

Introduction

People generalise and simplify. This goes for citizens, politicians and scientists alike. In science the “Occam’s razor” heuristic, stating that simple approaches are preferred over more complicated ones, and reductionism are the dominant research paradigms. This has led to linear and aggregated modelling. It is more and more acknowledged that this type of modelling has its limitations when complex real-world problems need to be investigated.

The complexity of the societal issues that are being worked on at Wageningen UR, such as global food security, balancing nature and agriculture, sustainable livestock production, and climate change adaption is such that the traditional modelling falls short. The nature of these societal issues is such that the physical and social aspects are structurally coupled. Interactions between society and production systems, with changing requirements, behaviour and emotions can give rise to unanticipated system behaviour.

The last decade complex adaptive systems theory has emerged as a new scientific paradigm to address the complexity of the societal issues Wageningen UR is working on. Within the Wageningen UR innovation programme Complex Adaptive Systems (CAS) we have developed innovative concepts and methodologies to apply the CAS paradigm. This booklet contains a brief overview of interdisciplinary projects that make use of CAS, such as Phytophthora control in potatoes, spread of antibiotics resistance, and innovative animal stable designs.

Hopefully, you will become inspired by the examples, concepts and ideas presented in this booklet.

more info: http://www.cas.wur.nl

Contact information

prof. dr ir. Arnold Bregt
Geo-information and Remote Sensing, Wageningen University
E arnold.bregt@wur.nl

prof. dr ir. Bas Kemp
Adaptation Physiology, Wageningen University
E bas.kemp@wur.nl

dr ir. Tim Verwaart
LEI, Wageningen UR
E tim.verwaart@wur.nl

What are Complex Adaptive Systems?

Central to the projects presented in this booklet is the paradigm of Complex Adaptive Systems (CAS). Systems are considered complex and adaptive when they consist of many components (such as humans, firms, farms, animals, plants etc.) that continuously act, interact, react, and adapt.

Examples of such systems are land use systems (or more general socio-ecological systems), agricultural systems, economic systems, urban systems etc. All these systems have a number of characteristics in common:

- Nonlinear behaviour: The rate of change continuously changes. Feedback processes are at the basis of this behaviour leading to many alternative possible developments. As a consequence CAS display a strong history dependence and high sensitivity to initial conditions. This makes the behaviour of CAS challenging to predict.
- Emergence: Components of CAS may individually show simple behaviour guided by simple rules that define relations with other components and the environment they are situated in. However, these relations give rise to self-organizing behaviour referred to as emergence. Emergent patterns serve as indicators for the behaviour at system level.
- Anticipation and Adaptation: System components change in order to correct or mitigate unwanted changes in the system. Moreover they may anticipate future changes in the system. Anticipation and Adaptation requires learning and reasoning about system developments.

The above characteristics make up systems where the sum is more than its parts, and where traditional reductionist approaches often fall short. Analysis and modelling of these systems focuses on understanding how a system reacts and how social processes influence the physical ones and vice versa.
A common approach to study CAS is by means of developing simulations using Agent Based Modelling (ABM). ABM describes the different components of a system as agents, which are autonomous entities that are capable of observing their local environment, communicate with other agents, and make decisions based on a set of predefined or evolving rules.

Contact information

dr George van Voorn
PRI Biometris,
Wageningen UR
E george.vanvoorn@wur.nl

dr ir. Arend Ligtenberg
Laboratory of Geo-Information and Remote Sensing, Wageningen University
E arend.ligtenberg@wur.nl


How to interfere in the complex system of antibiotic use?

The prevalence of antibiotic resistance in livestock has increased in the last decades. Human and animal health are seriously threatened. To push antibiotic resistance back, the use of antibiotics in livestock farming must be reduced.

However, antibiotic use is complex due to interactions of biological processes and farmers’ decisions. These decisions are not only driven by economic considerations, but also by motivations, cognitions and social networks. Little is known about integrated effects of such aspects on adaptation of the farmer's management behavior of antibiotic use. The Complex Adaptive Systems approach with agent-based simulation of both epidemiological aspects and social and economic motivations to apply antibiotics, can provide deeper insights into the drivers of antibiotic usage and the potential effects of interventions.

CVI and LEI, institutes of Wageningen UR, have developed an agent-based simulation of processes affecting the use of antibiotics in pig fattening farms and the resulting levels of MRSA prevalence. The simulation models farmers’ decisions based on their observations of health problems on the farm, information on antibiotic use and their beliefs and motivations. Farmers’ motivations are influenced by information on public health effects of antimicrobial use, pressure from peers, and incentives arising from policies. By integrating socioeconomic and epidemiological agent-based models, the simulation does not only inform policy makers and researchers on the effects on the application of antibiotics, but also on the resulting MRSA prevalence.

The simulation illustrates how the multi-disciplinary Complex Adaptive Systems approach developed by Wageningen UR can contribute to solving complex sociotechnical problems.

Contact information

dr Thomas Hagenaars
CVI, Wageningen UR
E thomas.hagenaars@wur.nl

dr Natasha Valeeva
LEI, Wageningen UR
E natasha.valeeva@wur.nl

Pressure on the supply chain

Currently agricultural supply chains are under pressure of economic impulses to reduce prices, yet at the same time there are societal demands to increase animal welfare, lower environmental impact, and improve food safety and human health aspects.

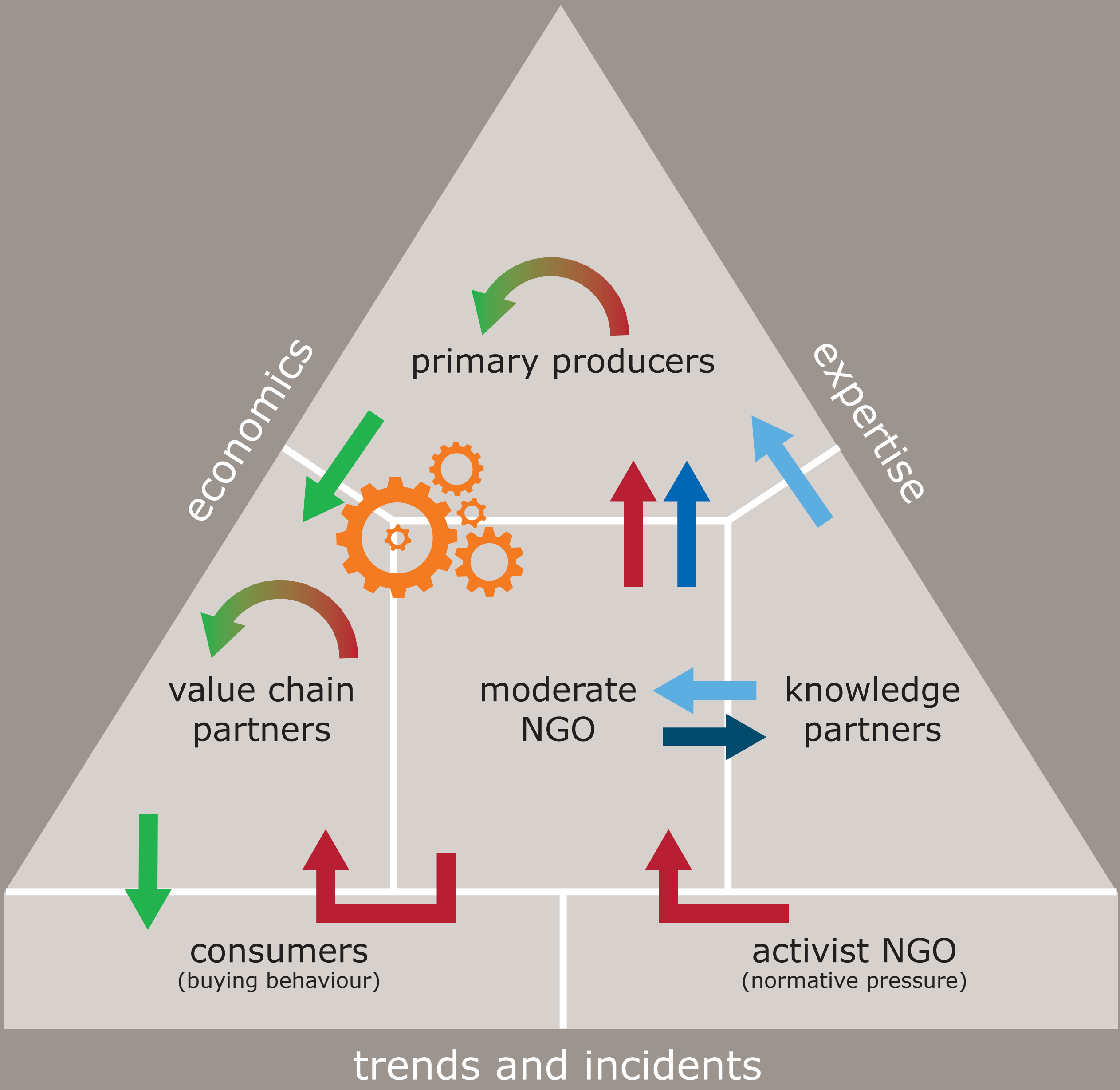
This sets additional requirements to the primary sector, but also offers opportunities to market new products. Producers may get a better price for products that comply with emerging demands. However, current supply chains usually cannot fulfil the new demands without innovations that cover on the one end newly designed inputs and production and distribution systems and on the other end require development of new marketing concepts. Such sociotechnical innovations require coordinated investments, with the associated risks. Consequently, they can only occur if sufficient pressure exists on all involved parties.

In particular for the farmers there is a serious risk that investments increase their production cost while the market is insufficiently developed to take up their production. Wageningen UR has applied the Complex Adaptive Systems approach to develop agent-based supply chain models. One model simulates innovations resulting from public opinion pressure, including effects of news items and NGO campaigns. Another model simulates the consequences of different types of supply chain organization on farmers' welfare and the fulfilment of social responsibility. The simulations inform policy makers and researchers about potential effects of interventions. Individual supply chain actors can use the simulations to explore their opportunities under different policy scenarios.

Contact information

dr Eva van den Broek
LEI, Wageningen UR
E e.vandenbroek@wur.nl

ir. Jan Buurma
LEI, Wageningen UR
E jan.buurma@wur.nl



Legend: pressure research solutions standards coordination innovation

2
40
5
1
2
30
30
40
1
2
3
4
5
1
2
3
4

Methods for analysing sensitivity and resilience of complex adaptive systems

Complex adaptive systems (CAS) modelling is an important approach for addressing scientific challenges involving interactions between social and ecological factors. CAS are composed of autonomous agents that interact with each other and their environment, and can adapt based on the outcomes of previous interactions.

Agent-based models (ABM) present a natural tool for modelling CAS, but analysing the behaviour of ABMs remains an important challenge. Traditional methods of model analysis are not well-suited to deal with typical CAS properties such as nonlinear behaviour, emergence, and anticipation and adaptation. New methodologies have been developed that address these CAS properties and thus are tailored to analyse ABMs.

One key emergent outcome resulting from the properties of CAS is resilience, i.e., the capacity of the system to cope with pressures while maintaining its identity and avoiding drastic consequences. It is important to understand the resilience of CAS to be able to anticipate the possible effects of human actions on coupled human-environmental systems (e.g., fisheries, agricultural systems). In order to do this methodologies are being developed that can help to analyse how resilience emerges from agent properties, and that can quantify resilience in ABMs. This information is crucial for those who are trying to find ways to increase the resilience of a system and better manage the system.

Contact information

Guus ten Broeke MSc
PhD-candidate Biometris,
Wageningen University
E guus.tenbroeke@wur.nl

Analysis of regime shifts and tipping points in land use systems

Land use systems can be found at different scales and are essential for the production of a wide range of goods and services, such as food and ecosystem services.

Because of the importance of these goods and services many governments design land use policies. Gradual changes in circumstances often result in unexpected non-linear responses of land use systems. An example of such an unexpected response is a regime shift. We define a regime shift as an abrupt change of the land use system due to a gradual change in a system driver such as policy or market prices. Regime shifts can lead to unexpected and undesired policy outcomes, which are hard to reverse.

To improve our understanding of regime shifts we use agent based modelling and mathematical programming techniques to analyse the processes of change in land use systems. Agent based modelling allows us to represent heterogeneous and autonomous decision making units (such as farmers), to study mechanisms such as interactions (e.g. farmers who influence each other) and feedbacks from different linked systems (such as social networks). These mechanisms lead to unexpected behaviour in land use systems which can eventually result in regime shifts. Mathematical programming allows us to study abrupt changes, which are the result of constraints becoming more or less binding. Due to the possibility to calculate shadow prices we can say something about the likelihood of a shift taking place. This allows us to study latent processes.

Contact information

Anouschka Groeneveld MSc
PhD-candidate Agricultural Economics and Rural Policy group/Land Use Planning Group, Wageningen University
E anouschka.groeneveld@wur.nl

Yang Chen MSc
PhD-candidate Laboratory of Geo-information and Remote Sensing/Land Use Planning Group, Wageningen University
E yang.chen@wur.nl

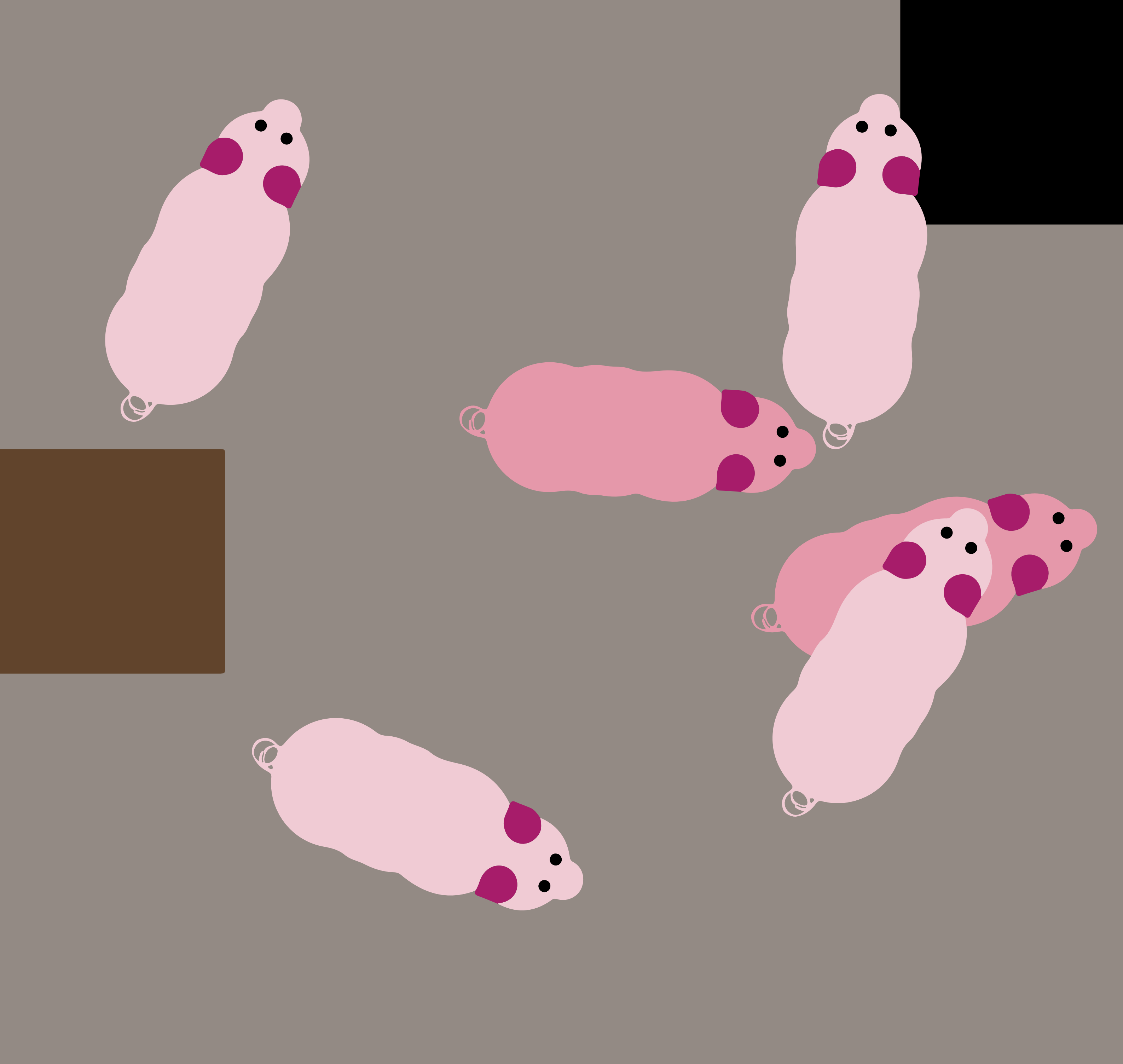
Simulating pig behaviour and the effect on the sustainability performance of pig production systems

Pig production has to deal with several sustainability issues, e.g. production costs, pig welfare and the impact on the environment.

Pig behaviour, such as tail or ear biting, indicate impaired welfare and might negatively affect production, whereas urinating and defecating behaviour affect ammonia emission and, hence, environmental farm performance. Occurrence of these behaviours emerge from the complex interplay among a whole range of internal (e.g. genetics, sex) and external (e.g. ventilation, feeding) risk factors. No models exist that allow a proper analysis of trade-offs and synergies among pig behaviour and associated sustainability indicators. Being able to do so would allow further optimization of pig production systems and taking deliberate decisions in trade-offs among sustainability issues, while avoiding costs of "real life experiments". Therefore, our study aims to understand pig behaviour and the relation with sustainability performance of pig production systems by using agent-based modelling. Agent-based modelling is a promising new approach in the study of farm animal behaviour and sustainability research. We develop agent-based models in which the behaviour of a pig emerges from an interaction between internal and external factors. These models give insight in the complexity of pig behaviour and the emergence of behavioural patterns. They are a first step in analysing the effect of behaviour on sustainability performance of production systems.

Contact information

Iris Boumans MSc
PhD-candidate Animal Production Systems group, Wageningen University
E iris.boumans@wur.nl



Designing disease resistant cropping landscapes

The case of potato and late blight (Phytophthora infestans)

Potato late blight (Phytophthora infestans) is one of the most damaging diseases in potato production and causes major losses in yield. This research focuses on the occurrence of late blight in the Netherlands.

The Netherlands are a large producer of seed, ware and starch potatoes. Climatic conditions are favourable for late blight which can lead to large outbreaks. The application of environmentally harmful fungicides is the most important control method. Sustainable management of the disease includes the use of resistant varieties which are developed by commercial breeding companies. However, when more farmers grow resistant cultivars there is an increased risk for resistance breakdown. Spatial allocation of cultivars could help to avoid loss of resistance, but this requires cooperation among stakeholders.

In this project we use a systems approach to identify sustainable management strategies for the control of potato late blight. Since the overall infection in a landscape depends on management strategies by stakeholders as well as disease epidemiology, we not only focus on ecological processes but also on decision-making concerning disease management. Agent-based modelling is used as a tool to identify effective and sustainable management strategies at the landscape level as well as the effect of decision-making strategies by stakeholders. These models integrate epidemiological models of potato late blight, agronomic data and stakeholder behaviour. Several scenarios can be explored that affect host-pathogen dynamics or decision-making of stakeholders such as climate change or policies. The results of the model will be used in workshops with stakeholders to show them opportunities for alternative action.

Contact information

Francine Pacilly MSc
PhD-candidate Plant Sciences Group/
Farming Systems Ecology,
Wageningen University
E francine.pacilly@wur.nl

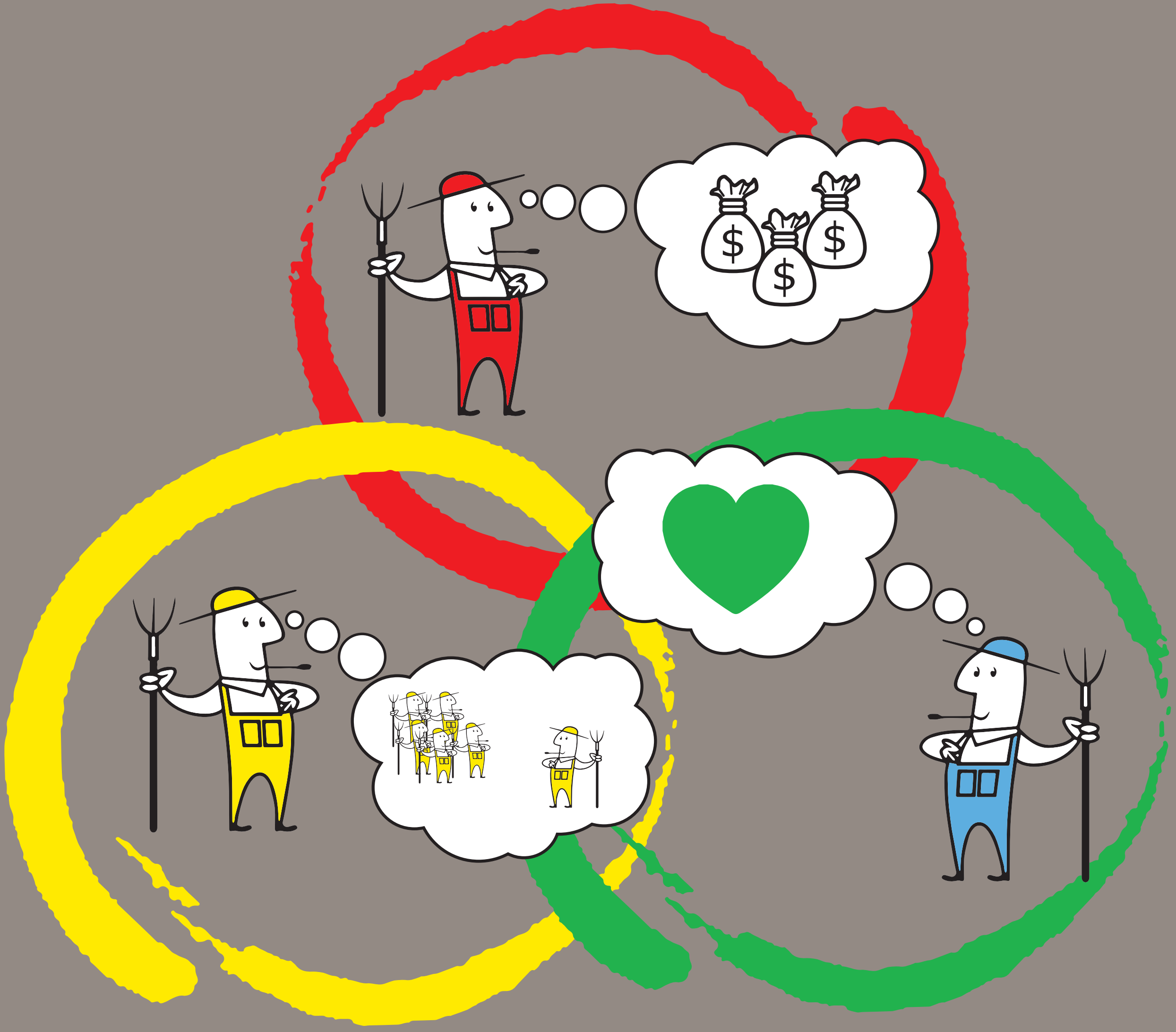
Economic and social feedback between landscape level and farm level processes

Transitions towards more sustainable agricultural landscapes requires collaboration among farmers to realise a green infrastructure. Our aim is to explore which factors can cause such transitions and make them persistent.

To this end we have built a model of a simple social-ecological network in which farmers differed with respect to economic, sustainable and social world views. In the model arable farmers could decide to replace chemical pest control by natural control through creating a green infrastructure on their farm. This farm level move towards sustainability can only be effective if the number of neighbouring farmers making the same adaptation exceeds a threshold.

In the most simple version of the model we found that social networks of farmers played an important role in the transition and can also prevent a fall-back to conventional farming, next to farm level costs. With an advanced version of the model, in which we built in individual and social learning in adapting farming as a response to an external change, we found that social learning prevented the system to fall back to conventional farming. In addition, the initial (stochastic) clustering of farmers who shifted to sustainability had a considerable effect on the number of sustainable farmers that persisted after the external change was taken away.

Our contribution to existing knowledge is that we combine economic and social feedback between landscape level and farm level processes and in the heterogeneity in farmer's attitudes.



Contact information

dr Anouk Cormont
Alterra, Wageningen UR
E anouk.cormont@wur.nl

dr ir. Nico Polman
LEI, Wageningen UR
E nico.polman@wur.nl


NeilJan
RJF

The role of social behaviour in the resilience of fisheries

Despite attempts to prevent overfishing, high fishing efforts remain in many fisheries. Current approaches to manage fisheries neglect important aspects of fisher behaviour, like the use of imperfect information, bounded rationality of fishers, adaptation behaviour, and the role of social factors in decision-making.

The resilience of fisheries against overfishing may be improved by an approach that considers fisheries as Complex Adaptive Systems in which the decision-making of fishers is affected by social behaviour and limited knowledge.

An agent-based model (ABM) was developed to simulate the decision-making of fishers (fishermen and companies) in the Philippine skipjack tuna (Katsuwonus pelamis) fishery. This decision-making includes social factors that were identified from interviews with stakeholders. Social factors that were found to have a clear effect on macro-level output (fishing effort, fish stock, and industry profit) are:

1. A strong resistance from fishers to sell their business under poor economic development resulting from traditional attachment to their business;
2. A social norm that has developed between fishers regarding fishing activities, which results in under-exploitation of fishing sites;
3. A high tendency for new companies to enter the business that is based on a bias in the information about the state of the fishery to potential entrants.

Although companies are motivated by profit, social factors and effects of limited information are also influential and should be considered in fishery research and management. Policy that considers these factors and their effects may be more effective in reducing fishing effort and improving the resilience of fisheries against overfishing.

Contact information

dr George A.K. van Voorn
Biometris, Wageningen UR
george.vanvoorn@wur.nl


Where should
the tomato go?

Analysing the robustness of the Dutch tomato producing industry

The Dutch greenhouse industry is situated in the economic heart of the Netherlands (Westland) and is an important driver for the Dutch export economy. It provides half a million jobs, has an annual production value of 4,8 billion Euro, and is responsible for an annual contribution of trade surplus of 4 billiard Euro.

Due to a combination of land pressure (urbanization) and economic recession, this industry faces increasing difficulty. Insufficient margins and increasing loan restrictions limit the opportunities for innovation and, as a consequence, negatively affect the Dutch competitive position.

The objective is to develop an ABM of the tomato production industry and to use this model to explore interactions between the producing level and other industry linked within the food chain. This enables us to analyse the robustness of the sector and to facilitate further development, by exploring how the sector interacts with trends in globalization, upscaling, local4local, slow food or out-of-home consumption, etc.

The concept behind this model is based on the concept of Grievink (2007), who distinguishes between levels of the production industry (supplying industry, greenhouse entrepreneurs, trading industry, buying desks, retail industry, and consumers) and the specific power relations between levels.

From our results, it is clear that besides the decisions from greenhouse entrepreneurs, many other forces influence the financial situation on the producing level. This type of multi-level modelling has not previously been done, and provides analytical means to search for sustainable intervention methods.

Contact information

Matthijs Danes MSc
Alterra, Wageningen UR
E matthijs.danes@wur.nl

The role of social interactions in the success or failure of innovations in the pork sector

Pork farmers are under pressure from society and the market. Whether or not farmers adapt to societal pressure and adopt innovations that improve societal issues like animal welfare, public health and environmental pollution, depends on different factors: their current resources, their personality, and social influence via their peers.

In this research we explore the factors, with a special focus on the role of social influence, that influence the success or failure of farmers' adaptation strategies to societal concerns. We look at this from a time-dependent context, meaning that farmers' behaviour can change over time, due to (the collective outcome of) other farmers' behaviour and their previous decision-making.

We combine different methodologies. We first used available literature and interviews to make an overview of the factors that influence farmer decision-making and identify the factors that change over time. Currently, we are building a game to be played with farmers, in which the players (1) should financially manage their individual farm, and (2) can collectively manage societal acceptance of the pork sector, through investment in strategies that can influence the societal acceptance of the pork sector, such as investment in transparency, distraction material and higher quality markets. Interaction between farmers during the game will be measured and used to build an Agent-Based model. The model will serve to explore the success or failure of innovations as a consequence of different forms of social influence between farmers: i.e. the role of leadership and norms.

Contact information

Floor Ambrosius MSc
PhD candidate, Information Technology Department, Wageningen University
E floor.ambrosius@wur.nl

Resilience

Most complex adaptive systems exhibit some degree of resilience. The exact definition of resilience differs per scientific discipline, but central is the notion of a system's ability to continue performing certain key functions.

Resilience can exist in the individual agents, for instance in the form of a capacity to buffer a shock or to adapt to new situations, but it can also emerge at a higher system level, even when the individual agents are not resilient. This latter notion is particularly interesting for complex adaptive systems, since these are generally shaped by the interactions between individual agents that are specialized in a certain task. Such specialization involves a risk at the individual level (i.e. low resilience), but brings about advantages for the system as a whole. Resilience, in such cases, means that a system can quickly reorganize itself after being exposed to a shock. Individual agents may not be able to deal with this shock, but the system continues to perform its functions as the remaining agents easily re-establish functional links between each other.

Resilience may be poor when a swift reorganization between specialized individuals is hindered, for instance by the fact that only few individuals exist with a certain necessary functionality. Resilience may be undermined by a gradual process, such as the elimination of redundancy in a system (i.e. many individuals having the same ability) or the movement towards a certain critical mass for maintaining a certain agglomeration benefit. In order to better understand such processes, we need to develop tools that allow us to translate theoretical concepts of resilience into operational metrics and indicators. Agent-based modelling of systems exhibiting varying degrees of resilience is an important first step towards this goal.

Contact information

dr Martha Bakker
Land Use Planning group,
Wageningen University
E martha.bakker@wur.nl