Modelling scenarios for sustainable agricultural development in an Austrian region

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Abstract

Sustainability research focuses on socio-ecological systems that emerge through the interaction of a society with its natural environment. Human decision-making plays a major role in every spatial and temporal aspect of land use. Decisions are made at multiple scales with feedback from one scale to another. Agent-based modelling is currently being explored as a tool for understanding the dynamics of socio-ecological systems in which decisions of actors influence biophysical dynamics, such as socioeconomic metabolism and land use. This paper investigates how agent-based modelling can contribute to local sustainability studies by encouraging transdisciplinary research and by structuring participatory processes that involve local stakeholders. It shows that agent-based modelling requires a detailed and structured knowledge of the system and both facilitates and depends upon the integration of relevant local stakeholders in the work of analysis. The representation of a case study examining how social and political interventions, such as the EU's Common Agricultural Policy (CAP), affect patterns of land use as well as socio-economic conditions in a specific rural region in Austria illustrates the research team's experience in designing a land-use model during a participatory process lasting three years. The model combines an agent-based module used to simulate farm households with a system dynamic module that simulates changes in land use and accordingly in substance flows, such as nitrogen flows. All decisions made by farmers are strongly affected by any changes in income in terms of subsidies and market prices. However, most of the decisions also depend on the time available for agricultural work and on the preferences of the younger generation regarding how much time they are willing and able to invest in farming. This indicates that the social dimension has great importance for any decision taken on the farm. Restrictions on the available time restrict actions and decision taken by the farm. Where only one generation is living on the farm, not enough working time is available to run the farm as a full-time operation. This is even less of an option where women are engaged in child-care. The younger generation will not accept a life without leisure time and without the freedom to make decisions. Finally, infrastructure, such as the child-care system, care for the elderly or the availability of (part-time) jobs in the region, places constraints upon the decisions and actions of farmers.

1. Introduction

In recent years, the notion that scientific efforts aimed at supporting decision-making on issues related to sustainable development require an improved understanding of the fundamental character of society-nature interaction has gained widespread support (e.g., (Kates et al. 2001)). Various attempts to define sustainability have emphasized different aspects of the problem, mostly depending on the discipline, professional background and personal interests of the researchers involved (e.g. (Brandt 1997), (Clark and Munn 1986), (Holling 1986), (Pearce, Markandya, and Barbier 1990), (WCED 1987)). Accepting the premise that sustainability is a question of society-nature interaction means that societies, natural systems and their interaction over time and space must be observed ((Haberl et al. 2004) to obtain answers for questions, such as what kinds of changes cause socio-economic activities in natural systems, what are the drivers for these changes and how can they be influenced.

Thus, sustainability research focuses on socio-ecological systems that emerge through the interaction of a society with its natural environment ((Fischer-Kowalski and Weisz 1999), Figure 1). Socio-ecological systems are inherently complex. Where changes to these systems occur, biophysical, social and economic components and their interactions must be considered to obtain greater understanding of the system dynamics at hand, thus helping to derive insights useful in supporting decision-making processes and in assessing why particular interventions may or may not be successful ((Matthews 2006)).

One complex and dynamic process linking natural and human systems is land use. Land use impacts directly on biota, soil, water and the atmosphere and is therefore environmentally highly relevant ((Meyer and Turner II 1994). Land use is currently changing around the globe, often rapidly, and these changes are seen as a pervasive driver of global environmental change, in many places jeopardizing biodiversity, the integrity of vital ecosystems or eroding the capacity of ecosystems to deliver essential services. Land use patterns are simultaneously influenced by natural preconditions such as vegetation, land forms, climate or soil and by socioeconomic patterns and processes such as family structures, diets, economic incentives and preferences, the structure of the economy, property rights, subsidies, markets and many others (Wrbka et al. 2004). Land-use change models facilitate more detailed understanding of this process and have been defined as tools to support the analysis of the causes and consequences of land-use change ((Verburg et al. 2004). However, land-use change models are not only capable of helping to understand patterns and dynamics of land use, but can further support the analysis of socio-economic patterns and processes that determine land-use change. In this case, land-use change models address the question of how a socio-ecological system has evolved into its current state and how it might change in the future. In other words, how are interactions between the social and the natural system changing, and what implications do these changes have for the state of the socio-ecological system? (Agarwal et al. 2002).

Human decision-making plays a major role in every spatial and temporal aspect of land use. Decisions are made at multiple scales with feedback from one scale to another. A review by (Parker et al. 2003) focuses on agent-based models as tools for representing human decision-making. Agent-based modelling is currently being explored as a tool for understanding the dynamics of socio-ecological systems in which decisions of actors influence biophysical dynamics, such as socioeconomic metabolism and land use, and vice versa (e.g. (McConnell 2001), (Janssen 2004)), as they are capable of simulating the aggregate outcomes that result from decisions made by many individual actors.

As mentioned above, sustainability science must focus on society-nature interaction, since neither a focus on social parameters nor a focus on biophysical parameters alone would be sufficient to derive the kind of information required to support sustainable development. Moreover, in order to be able to focus research processes on the concrete needs of key actors or stakeholders, a specific approach is required that allows actors to participate throughout the entire research process, starting with defining the problem to be analysed and ending with planning or initiating specific interventions. Participation of this kind is key to enabling social actors or social systems to learn from or be stimulated by the research process (see, for example, (Hare and Pahl-Wostl 2002), (Pahl-Wostl 2002)).

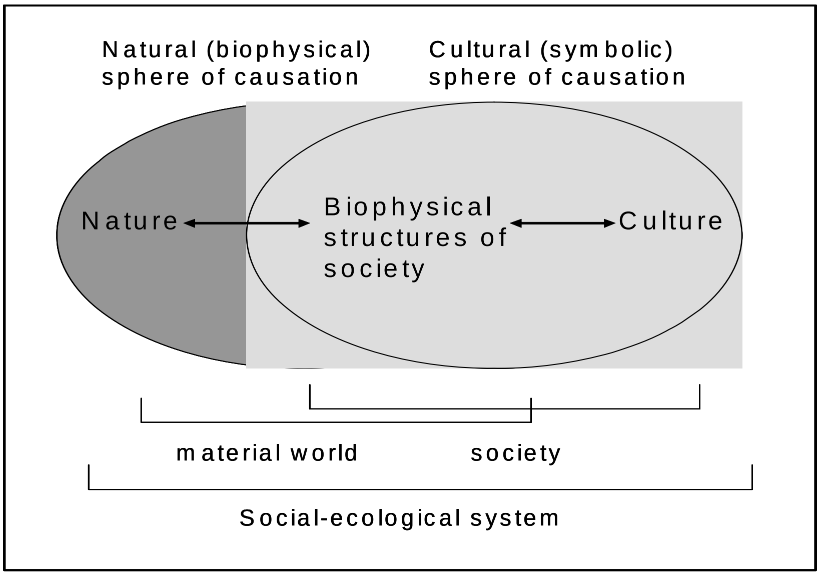
This paper investigates how agent-based modelling can contribute to local sustainability studies by encouraging transdisciplinary research and by structuring participatory processes that involve local stakeholders. It shows that agent-based modelling requires a detailed and structured knowledge of the system and both facilitates and depends upon the integration of relevant local stakeholders in the work of analysis. The representation of a case study examining how social and political interventions, such as the EU's Common Agricultural Policy (CAP), affect patterns of land use as well as socio-economic conditions in a specific rural region in Austria illustrates the research team's experience in designing a land-use model during a participatory process lasting three years.

2. *Agent-based modelling and sustainability research*

The heuristic concept of socio-ecological systems (Fischer-Kowalski and Weisz 2005) contributes to current sustainability research by taking the emergent character of biophysical, symbolic and social systems as well as of the interactions of these systems into account. Two spheres, one depicting a 'natural' or 'biophysical' sphere of causation governed by natural laws and a second representing a 'cultural' or 'symbolic' sphere of causation reproduced by symbolic communication, can be identified. These two spheres overlap, constituting the 'biophysical structures of society', which are subject to both the cultural and the natural sphere of causation. Thus, society constantly reproduces its symbolic as well as its biophysical structures by interacting with its biophysical environment ((Weisz et al. 2001), p. 121)).

Figure 1: Conceptual (heuristic) model of society-nature interaction

Source: (Fischer-Kowalski and Weisz 2005)



One approach to empirically describing these biophysical interactions is that of ‘socio-economic metabolism’ (e.g., (Ayres and Simonis 1994), (Fischer-Kowalski 1997), (Fischer-Kowalski et al. 1997), (Matthews et al. 2000)). This analyses material and energy flows between the biophysical structures of society and other components of the biophysical sphere of causation. The central idea of the metabolism approach is to view societies as a physical input-output system, drawing material and energy from its environment, maintaining internal physical processes and dissipating wastes, emissions and low-quality energy to the environment.

The analysis of material and energy flows related to economic activities alone is not sufficient to capture society-nature interactions. One important aspect not adequately covered by the metabolism approach is land use, which is among the most important socio-economic driving forces of global change ((Meyer and Turner 1994)). Land use can be conceptualised as the ‘colonisation of nature’ ((Fischer-Kowalski and Haberl 1997), (Haberl et al. 2001), (Weisz et al. 2001)), an approach that emphasises the fact that these human interventions into ecosystems are undertaken deliberately with the intention of modifying natural systems according to society’s needs and wants. Colonisation intensity in ecosystems can be analysed empirically by comparing currently prevailing ecosystem patterns and processes with those that would be expected without human intervention. The two approaches, ‘socio-economic metabolism’ as well as the ‘colonisation of nature’ have led to a huge number of empirical studies on land-use patterns as well as on material and energy flows. These studies represent a wide variety of approaches, focusing on the local, regional, national as well as on the global level and dealing with historical, current and future developments. Combinations of the concepts of ‘socio-ecological systems’, ‘socio-economic metabolism’ and ‘colonisation of nature’ provide a sound theoretical and empirical basis for integrating approaches from natural sciences, social sciences and the humanities and, thus, for adequately understanding sustainability issues.

Existing scientific modelling methods mostly reflect theories and concepts developed within single disciplines. Most models focus on either on ecological, social or economic aspects, and those that have a broader approach often have at their core either an ecological or an economic model extended by certain modules to establish at least some relations to other aspects of the system to be modelled. When considering what kind of modelling methods might be able to meet the requirements of modern sustainability research represented by the socio-ecological approach, we believe that *integrated* models are suitable because they are capable of taking into account social, economic and ecological aspects and thus of interlinking humanities, social science approaches and concepts from the natural sciences ((van der Leeuw 2004)).

Agent-based modelling (also referred to as ABM) offers one such integrated approach as it allows researchers to explicitly link biophysical and socio-economic processes within a socio-ecological system. Agent-based models are defined at the levels of individual actors and their interactions with each other and with their environment ((Epstein and Axtell 1996), (Kohler and Gumerman 2000), (Parker et al. 2003)). Components of these models are one or more types of agents and the environment in which the agents are embedded. Agents may be individuals (e.g., householders, farmers, developers) or institutions (e.g., NGO´s, firms). Specifying agents requires defining their state (e.g., preferences) and the rules upon which their decision-making is based. The behaviour of individual agents is related to their interactions with other agents and with their environment. Environmental change follows its own dynamics and is also influenced by the aggregated agents' behaviour.

Agent-based models represent a qualitatively different approach to mathematical and statistical approaches and offer potential benefits for new land-use and land-cover change models ((DeAngelis and Gross 1992). The agents and their interactions are mainly described as constituting the proximate causes of land-use change ((Geist and Lambin 2001), although other causes may be analysed as well. The main advantage this type of model offers is that it facilitates the analysis and understanding of processes. From a theoretical perspective, agent-based models can be described as land-users' models rather than land-use models. The land users, in this case farmers, represent the starting point and spatial decisions of individuals or groups of individuals are used to define the land-use changes (Koomen et al. 2007). Human decision-making and interaction between agents and their environment constitute the central elements of agent-based models. A recent overview by (Parker, Berger, and Manson 2002) on agent-based models for land-use changes shows different applications from around the world, while the choice behaviour therein is modelled with relatively simple rules.

Two further aspects make ABM valuable for sustainability research: Firstly, ABM encourages structured participatory processes, as relevant actors are involved in the design and evaluation of the model throughout the entire research process. This facilitates the design of problem-oriented research that is close to people's everyday life experiences – a precondition for ensuring practical use may be made of scientific research. Secondly, special aspects such as gender aspects, intensively discussed in the context of developing countries (Leach &Green 1997, Gupte 2002) but widely ignored within European sustainability research, can easily be integrated into model designs as well as into participatory processes.

3. The Case Study

3.1. Research focus

The purpose of this case study was to evaluate how social and political interventions affect patterns of land use as well as socio-economic conditions in rural regions, by developing an agent-based model embedded in a participatory project design. The model is used here to show the effects of the EU´s Common Agricultural Policy (CAP) reform 2006 and further changes in subsidy payment structures on land use in rural communities.

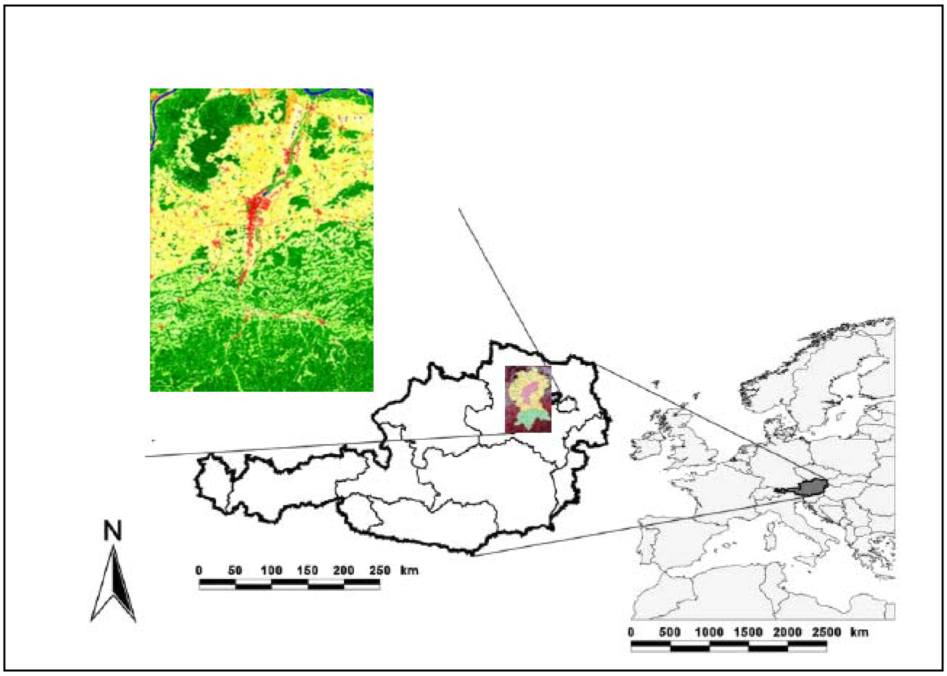
Currently, the CAP shifts from being coupled to defined products to decoupled transfer payments – a change of political forces influencing agricultural land use. Farmers will no longer need to plant certain crops or raise livestock in order to obtain financial support. In the future, production decisions will be less influenced by product-specific incentives and consequently market signals will become more important for production and management decisions ((Schmid Erwin and Sinabell 2007). The CAP reform came into force on 1 January 2006 and provides incentives for farmers to shift from the formerly prevailing situation according to which special products were promoted towards an allocation of resources according to market demand and prevailing natural conditions. Consequently, agricultural policy affects regional land use and shares land-use systems, which in turn influence the socio-economic situation of land users.

The agent-based model was conceptualised and implemented with the aim of analysing the impacts of the CAP reform on the situation in the research area, and assessing how changes in subsidy payments influence decision-making processes of farmers. In this regard, the following questions were addressed: What are the influences of changes in subsidy payments on land use in general? What are the main effects of the CAP reform 2006 on the socio-economic and ecological situation of agriculture in the region? How do political interventions affect forms of agricultural production, farm income and family working patterns? Integral to the research was the challenge to involve regional actors in a participatory process to elaborate the research questions listed above. The goal of this participatory process was to support local stakeholders in their decision-making.

3.2. The region

The model was applied to a case study in a rural region of Lower Austria (the Traisen valley). The selected region, like many rural regions in Austria and in Europe as a whole, is confronted by numerous environmental and social problems, such as accelerated structural change and a high dependency on subsidy payments, mainly regulated at a supranational level (European Union).

Figure 2: The study region St.Pölten in the north-east of Austria (Lower Austria)
(Quelle: (Wrbka et al. 2003))



The Traisen valley region in Lower Austria as defined here consists of 29 municipalities along the Traisen river, surrounding Lower Austria's capital, St. Pölten (Figure 2). The study region has an area of 700 km^2 and is characterised by diverse land use. The less hilly northern part of the region is dominated by cropland and wine production. The alpine character of the landscape in the southern part generally allows only for milk production, pastures and forestry. Forest holdings occupy over 200 km^2 and milk production occupies a further 100 km^2. The remaining 400 km^2 are distributed between all other production types. The farms situated in the study region represent all farming types commonly practised in Austria. Most of the farms have a size of between 20 and 50 hectares. Nearly half of all farms are run by full-time farmers, while the remainder are managed by part-time farmers of whom there has been a clear increase in numbers over the last 10 years. Farmers in the Traisen valley region have to deal with numerous social problems, such as accelerated structural change and a high dependency on subsidy payments. The existence of ongoing structural change in the agricultural sector and the willingness of relevant stakeholders to co-operate were crucial for the selection of the region.

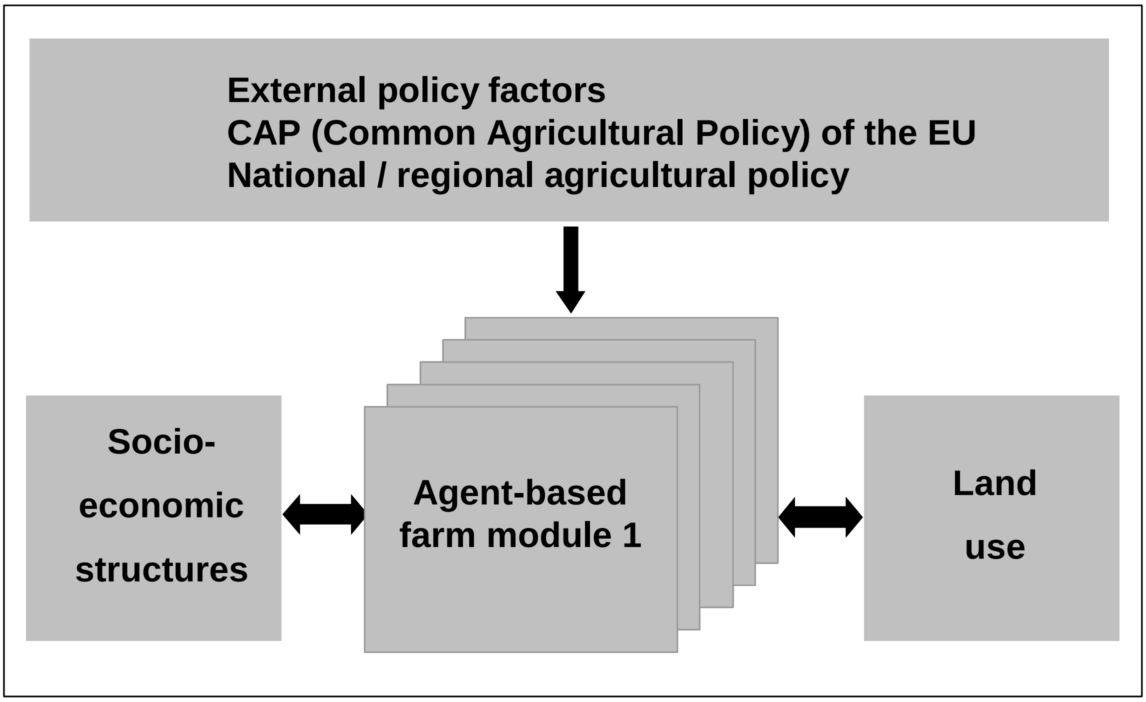
3.3. The model concept

The model combines an agent-based module used to simulate farm households with a system dynamic module that simulates changes in land use and accordingly in substance flows, such as nitrogen flows (Figure 3). Agent-based models, in general, enable a formalised representation of social systems and consist of virtual agents and their environment. Agents interact with both other agents and their environment. The term 'environment' in this case is not limited to the natural environment, but includes the socio-economic situation of the region as well. Agents have a certain knowledge of the system they belong to ((Ferber 1999)). The preferences and behaviour of the agents are affected by the system in which they are embedded and by changes in their environment. Simultaneously, the dynamics of the whole system depend on the individual behaviour of each agent. Interactions between the agents have direct impacts on both the socio-economic situation and on land use.

The dynamics of the model are driven by assumptions regarding changes in the external conditions of agricultural policy on different levels. Changes in subsidy payments and price relations have direct impact on family farmsteads as agents of the model. According to these changes, each farm evaluates its situation and makes decisions concerning agricultural production. These decisions in turn affect the socio-economic situation of the farm and its ecological impact. Consequently, summarising all single decisions within the model as a whole allows changes in socio-economic structures, such as income and workload of farmsteads, as well as changes in land use in the entire region, to be simulated.

Figure 3: Overview of the integrated model

source: own diagram



The first question asked was: How should agents be characterised in order to allow an analysis of socio-economic actions and dynamics and their link to the biophysical environment? Referring to sustainability's three main dimensions, we defined each agent in terms of three dimensions: social, economic and ecological.

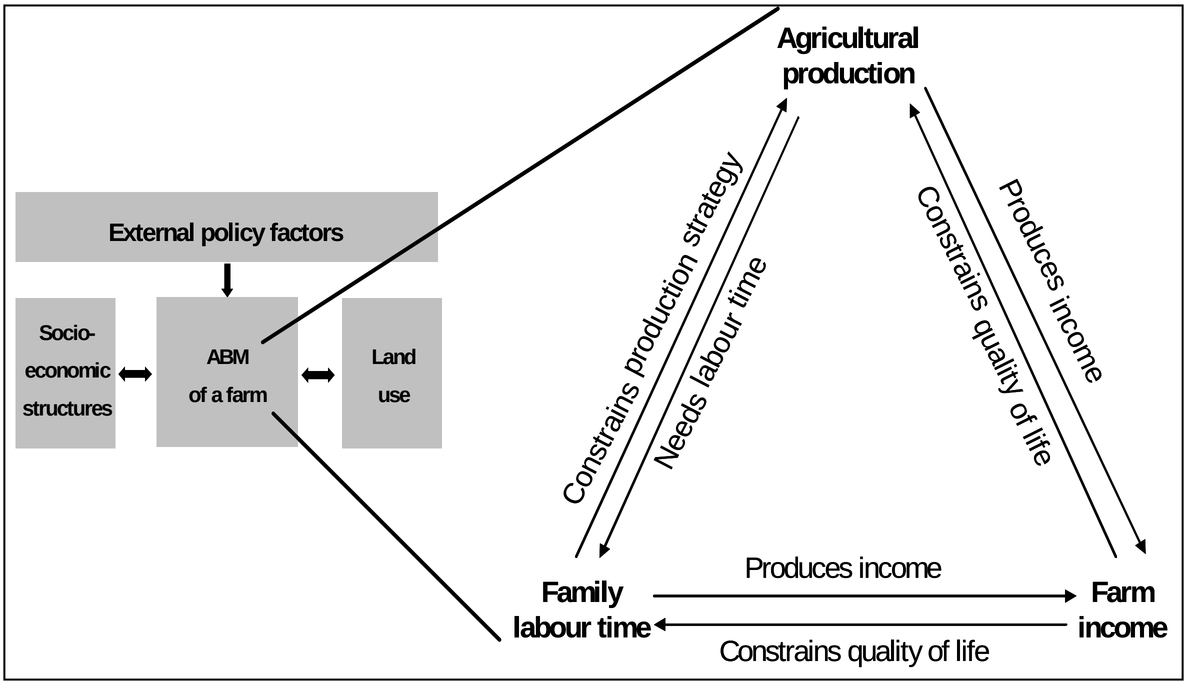
At a local level, the *ecological dimension* can be defined as the way land is used. The *social dimension* may be described as the form and quality of life of a specific social unit in a specific area. The *economic dimension* can be identified as the monetary income of a particular social unit (household, person or community). In applying these to our agent farmsteads (Figure 4), the following indicators were chosen to characterise the three dimensions:

1. Ecological dimension: Agricultural production, such as land use (area of cropland, forest and grassland and the level of intensity of use) and livestock.
2. Economic dimension: Income of all family members living on the farm.
3. Social dimension: Family labour time necessary for production and reproduction, with a special focus on sexual division of labour.

The three dimensions are highly interdependent. This interdependency represents the decision-making process of each farm, as shown in the following figure:

Figure 4: The magic triangle of the "agent" farmstead

source: own diagram



Regarding the interdependency between land use and time use, every land-use strategy requires a specific amount of working hours. In this study, land-use strategy implies a shift between the three land-use categories of cropland, grassland and forest according to changing subsidy and price conditions. Additionally, the definition of land use takes the intensity and the type of livestock farming into account. For this reason, we defined three categories of land-use intensity:

(1) Intensive use means that the farm fertilizes its areas more than subsidy requirements allow. For this reason, the economic dimension of the farm can only profit from agricultural production and is highly dependent on product prices, because no subsidy payments are received. This category, according to expert assessment, represents 3 percent of all farms included in the model.

(2) Conservative farms operate within the guidelines of national and EU subsidies. Accordingly, these farms receive a high amount of their income through subsidy payments. Approximately 90 percent of all farms in the study region belong to this group.

(3) The remaining 7 percent of all farms in the study region consist of extensively managed farms employing organic farming methods. These farms receive special subsidies for organic farming and achieve special prices for their organic products.

According to the number and ages of the people living on a farm, only a certain amount of working hours are available, which in turn constrains the extent and intensity of land use. At the same time, as land use requires working hours, this constrains the time budget that can be used for other activities that are not related to agricultural production, such as working time on the labour market, leisure time or reproduction.

Concerning the interdependency between land use and income, each agricultural activity generates a certain amount of income, which is limited according to the quality and quantity of the land available. The income, on the other hand, determines and constrains the way land can be used: If more income is required, (more) land is (if possible) used in a different way (e.g. more intensively). Conversely, high income allows available agricultural land to be extended.

Concerning the interdependency between time use and income, time, defined as working time, determines the amount of income. It also constrains the amount of income, as a limited amount of working hours is available (due to lifetime and number of inhabitants). In turn, the amount of income constrains activities in leisure time or requires greater working time. Every change in the way income is earned, for example, more time may be spent carrying out a job outside agricultural production with a higher hourly income, has a clear impact on the economic dimension.

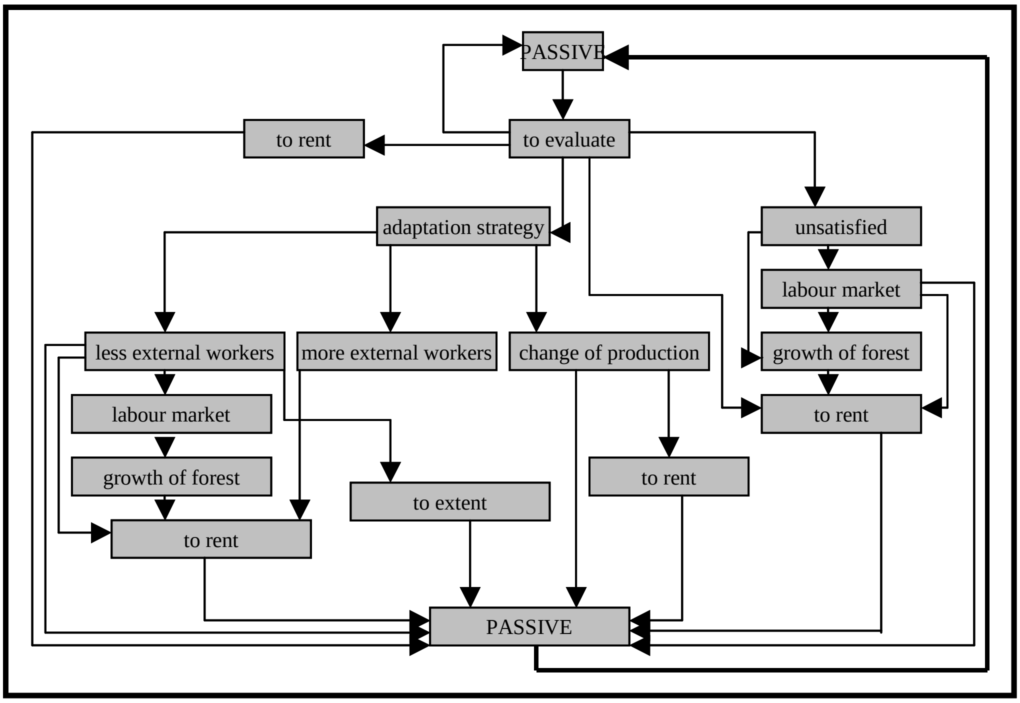
All three dimensions possess inherent features and dynamics as they are influenced or even regulated by their internal structure and their environment. The way time is used strongly depends on the quality of the system itself (e.g. how many children and old people must be cared for). It further depends on the social/cultural system to which a social unit belongs (e.g., social values, traditions and norms, or the infrastructure available). Female working time, for example, is freed up by the availability and usage of an adequate child care system is available. Income is highly influenced by the dynamics of economic systems (e.g., market, prices and subventions). Finally, land use is constrained by the specific features of the local ecosystem (e.g., rice does not grow in arid areas) as well as by global environmental dynamics.

The analysis of decision-making processes within this triangle requires the implementation of each agent with its internal structure in terms of family structure, such as family members living on the farm, their gender, age and role on the farm (i.e., agricultural working time). Single farms of different production types are implemented as agents, which themselves are influenced by changes to their environment and by changes to their internal structures (e.g., birth, death, marriage). Consequently, farms change their production strategy in terms of intensification or farm size by interacting with their neighbours via a regional land rental market. Beside extension or reduction of land, further reactions are implemented in the model, including the following examples: intensification and technological innovation of production,increase in farm size and decrease in number of farms in the region,diversification of production,increase in non-agricultural labour time, orabandonment of farms

The question of under which conditions and at what time a certain farm chooses one of these reactions is raised. Each agent in the model follows a specific decision-making tree. Whenever a farm household fails to reach a minimum of income or exceeds a maximum of working hours it seeks to change its situation by making one of the reactions listed above. Most of these options are actions that every agent can take without any interactions with other agents in the model. However, since the extent or reduction of land affects other agents, a rental market was implemented in the model. Every year, after evaluating its economic and social situation, each farm that has or wants to rent or lease land ‘leaves a message’ with the rental market. The model calculates demand and supply for land and allocates it to the single farms on as effectively a basis as possible. Those farms with requests that cannot be in a certain year can either take another action or remain passive for the year in question and react again the following year. From the point of modelling requirements, it would have been much too complex to implement direct negations between the agents. Decision-making trees are used to determine what kinds of reactions with a specific probability under which circumstances are likely to be taken.

Figure 5: Example of one decision-making tree implemented in the model

source: own diagram



The design of the decision-making trees as shown in Figure 5 as well as all other components of the model were developed together with local actors by means of a participatory process.

3.4. Models in participatory processes

Sustainability research that takes into account local actors' requirements and seeks to be implemented requires specific research methods that allow actors to participate throughout the entire research process. This entails defining a common research question that is to be analysed and planning or initiating specific interventions. This approach may enable social actors or social systems to learn throughout the research process. A transdisciplinary research design and a structured participation process are the key elements of sustainability research(see, for example, (Jahn 2005), (Brand 2000) 2000, (Hare and Pahl-Wostl 2002), (Pahl-Wostl 2002)).

Nevertheless, social goals and visions for the future must be translated into scientific categories and variables in order to become useful for the research process, that is, they have to be scientifically operationalised and, in the case of this study, be translated into a formalised modelling language.

In this study, relevant regional actors were involved in the modelling process right from the beginning. Interviews, focus groups and workshops allowed for research questions, model assumptions and model design to be discussed.

Table 1: Regional and non-regional actors involved in the participatory process

source: own description

Institution / group of actors	**no. of interviews**
Farmers	7
Agency of agriculture	4
Experts of federal agency of agriculture	4
Provincial government	5

Throughout the research, the participatory process contributed to and reflected on the information required for the design of the agent-based model. In turn, the agent-based model was applied as a guiding tool in the participatory process to help local actors reflect on the present and the future as well as in developing strategies and policy priorities.

At the beginning of the process, 20 guided interviews with various experts from the provincial government, federal government and representatives of the agency of agriculture as well as female and male farmers were conducted. In combination with a broad literature research on the CAP reform ((Geser 2004; Kirner 2003; Schmid Erwin and Sinabell 2007)) and its expected impact on agricultural activities, these interviews were an effective instrument to establish contact with relevant actors, to gather local knowledge concerning our research questions and to stimulate the interest of actors, giving them the feeling that the ongoing research was relevant to them and that they could play an essential role in the research outcome.

A second element in the participatory process was a series of focus groups with female farmers and experts (Littig and Wallace 1997), aimed at gaining insights into gender-related issues on farms. Twelve participants convened to discuss issues and concerns about decision-making processes, time-use and workload in agricultural households. The group held four meetings, each lasting about three hours, during an 18-month period.

The process of the focus groups was adapted to the participatory process as a whole. The intention of the first meeting was to test pre-defined hypotheses concerning the ratio between income and working time of men and women. The outcomes of the first focus group meeting and the information concerning actors' motivations and behaviours derived from the interviews informed the development of the first version of the ABM design. At that stage of model building the first simulation runs had to be evaluated. Several evaluation methods are available. One is the discussion of outputs with actors followed, if necessary, by a redesign and 're-formalisation' of the ABM. The task of the subsequent focus group meeting was accordingly to discuss the design of the model, where insights that had been generated so far were translated into formalised language and diagrams. Concrete decisions on relevant model outputs (e.g., labour time per farm, cropland area per farm, etc.) and adjustable model parameters required were taken together with the stakeholders. An important part of the process was the development of 'storyline' scenarios for the region. Finally, the thoroughly designed model and results of impacts of different actions under different framework conditions provided the basis for discussions.

3.5. Results and Discussion

Concerning land use, different model runs show that in any case, even if the subsidy payments rise in the following 20 years, the land area used for agriculture will decrease by around 30-60% of the current area. Especially in the grassland part of the region, the current trend of declining farm numbers is set to continue. As expected, increases in subsidy payments would slow down this trend. The number of farms is decreasing faster than the area of agricultural land because average farm size is expected to grow. In any case, by the end of the 20 years model run fewer but bigger farms are projected to dominate the agricultural sector, although some small farms, especially organic farms, will find a niche that allows them to survive. The intensity of production is mainly regulated by the conditions of the subsidy system. Besides the CAP subsidies, most of the farms in the study region are highly dependent on the national subsidy, ÖPUL, which is paid out to farms meeting specific cultivation requirements. Therefore, any change in these subsidies directly influences the intensity of cultivation of more than 90% of all farms. Generally, the effects of changes in the national subsidy structure are markedly greater than the effects of the CAP payments, not at least because the amount of national subsidy payments clearly exceeds those of the EU subsidies. Surprisingly, even if the amount of subsidies for organic farming and the prices of organic products were to rise, the number of organic farms would grow only marginally. No great shift in farming types will take place in the part of the region dominate by cropland. First of all, the biogeographic conditions support the production of permanent crops. In addition, permanent cropping can also be carried out while working on the non-agricultural labour market and delivers additional income. In contrast, in the grassland-dominated regions, a shift of production types seems likely. Keeping livestock means a high input of labour time, particularly in the case of dairy herds that require a high number of working hours, combined with few options regarding income. Therefore, the current trend of shifting milk production to meat production will continue. Similarly, the shift from meat production to food production that does not involve keeping livestock is set to go on. In general, a trend towards less time-intensive production types is observable. These results support the hypothesis that together with income, time is one of the most important factors that determine decision-making processes concerning production strategies. The average income per person will increase and, in most cases, the amount of non-agricultural income will rise. The amount of the agricultural income as a proportion of total income represents nearly 50% only where the situation of the agricultural sector is improved by rising subsidies and rising prices for agricultural products. Even if, in the same model run, the labour market conditions improve clearly in terms of wages and infrastructure, many farmers would decide to continue with agricultural production.

Table 2: Overview of the most important results

source: own description

	Initialization	Scenario trend	Scenario sust	Scenario glob
Storyline		Prices for conventional and organic products are stable, subsidies reduce about 20% over the next 20 years, situation on the regional	Prices for all products rise by 10%, subsidies increase also by 10%, situation on the regional	Prices for all products decrease by 20%, subsidies reduce to 0% over the next 20 years, regional labour
Number of farms	2,987	-48%	-36%	-70%
Number of organic farms	232	-43%	-14%	-52%
Number of intensively managed farms	87	-67%	-50%	600%
Number of conventionally managed farms	2,668	-48%	-37%	-95%
Number of part-time farmers	1,537	-46%	-28%	-66%
Number of full-time farmers	1,450	-49%	-43%	-76%
Non-agricultural working hours per year per farm [h]	2,725	160%	115%	214%
Agricultural working hours per year per farm [h]	3,390	18%	19%	45%
Average size of farms [ha]	20	24%	16%	17%
Agricultural crop land area [ha]	14,297	-27%	-13%	-62%
Agricultural grassland area [ha]	29,696	-37%	-26%	-75%
Managed forest area [ha]	42,688	-36%	-27%	-62%
Number of dairy cow	15,776	-15%	-9%	-50%
Number of cattle	35,032	-30%	-19%	-65%
Number of pigs	1,508	-42%	-33%	-72%
Annual income per person per year [Euro]	13,368	94%	119%	83%
Non-agricultural income per person per year [Euro]	6,095	169%	162%	176%
Agricultural income per person per year [Euro]	2,920	-2%	114%	52%

To sum up, all decisions made by farmers are strongly affected by any changes in income in terms of subsidies and market prices. However, most of the decisions also depend on the time available for agricultural work and on the preferences of the younger generation regarding how much time they are willing and able to invest in farming. This indicates that the social dimension has great importance for any decision taken on the farm. Restrictions on the available time restrict actions and decision taken by the farm. Where only one generation is living on the farm, not enough working time is available to run the farm as a full-time operation. This is even less of an option where women are engaged in child-care. The younger generation will not accept a life without leisure time and without the freedom to make decisions. Finally, infrastructure, such as the child-care system, care for the elderly or the availability of (part-time) jobs in the region, places constraints upon the decisions and actions of farmers.

4. Conclusions

The experiences gathered during our case study show that agent-based modelling as a tool for integrating social and natural science supports sustainability research for several reasons.

Firstly, even though socio-ecological systems may be too complex to ever be adequately represented by formal models, the very process of constructing the model is of great help in fostering interdisciplinary integration and mutual learning in interdisciplinary teams ((van der Leeuw 2004)). This matched entirely with our experience. In particular, the application of the sustainability triangle required that at least three disciplines, in this case, ecology, social science and economy, were represented on an equal basis. To define the interdependencies between the points, of the triangle extensive discussion between researchers of all disciplines was needed while designing the model.

Second, modelling provides the opportunity to integrate aspects that are important but often neglected within sustainability research, such as the gender perspective. The fact that we had to define each agent or farmstead in terms of its internal structure as represented by family members and their income and time resources facilitated the integration in the model of differences between men and women and their role at the farm.

Finally, modelling encourages transdisciplinary research design and structures participative processes since it requires active and constant cooperation between researchers and actors over a long period of time. A transdisciplinary research design differs from classical research approaches since it has to be more flexible in various respects (e.g., definition of research goals, selection of actors involved, milestones planned and methods applied). As experienced in our case study, modelling in cooperation with the actors helps to achieve both structure and flexibility, allowing for regularly reflection upon the research design and outcomes. Furthermore, the active and constant cooperation over a certain period of time required by the modelling process gives actors the chance to constantly observe and actively shape scientific research, making it more problem-oriented and of greater relevance to 'real life'. The regularity of meetings and the shared goal, that is, building a model that is close to the actors' reality, helps actors to identify with the ongoing research, to understand the everyday life experiences of themselves and others and to formulate possible problem-solving strategies relevant to their own situation. All these aspects taken together make agent-based modelling an instrument potentially able to contribute to local sustainability studies of greater scientific and practical use.

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