Interdisciplinary Modelling and Assessment of Multifunctionality

René Borresch[1], Bernd Weinmann[2], Friedrich Kuhlmann[2], Michael Schmitz[1]

[1] Institute of Agricultural Policy and Market Research, Justus-Liebig-University Giessen, Germany
[2] Institute of Agricultural and Food System Management, Justus-Liebig-University Giessen, Germany

Contribution appeared in Arfini, F. (Ed.) (2005) "Modelling Agricultural Policies: State of the Art and New Challenges", proceedings of the 89th EAAE Seminar, pp. 330 - 350

February 2-5, 2005

Parma, Italy

Interdisciplinary Modelling and Assessment of Multifunctionality

Dipl.-Ing. agr. René Borresch[*], Dr. Bernd Weinmann[**],
Prof. Dr. Dr. h. c. Friedrich Kuhlmann[**], Prof. Dr. P. Michael Schmitz[*]

Abstract

The current public and political discussion concerning multifunctionality of landscapes calls for decision support systems, which illustrate the consequences of different courses of action. The paper presents such a system for evaluating landscapes combining the land use model ProLand, the ecological model ANIMO, the hydrological model SWAT and the valuation framework CHOICE. Main focus is on ProLand and CHOICE.

Changes in land use, value added, labour input, gamma diversity, direct water flow and a corresponding cost-benefit analysis are presented for a scenario of changing field sizes in a study area.

Keywords: Multifunctionality, Modelling, Decision support systems, Cost-benefit analysis, land use.

Introduction

The term "multifunctionality" is at the centre of the political and public discussion accompanying the increasing interest in protecting landscapes including not only economic and ecological but also cultural and social aspects. Deciding about future developments or influencing current trends towards protecting or correcting multifunctional aspects of landscapes is an enormous task. Politicians have to choose among different future development paths as they implement strategies or policies. The challenge for science is to develop tools to assist in the decision process by showing the consequences of different policies. In the discussed case specifically land use models are needed (Bockstael, 1996). Changes in landscape functions are caused by

---

[*] Institute of Agricultural Policy and Market Research, Justus-Liebig-University Giessen, Germany.
[**] Institute of Agricultural and Food System Management, Justus-Liebig-University Giessen, Germany.

changes in land use. As strong interactions between economic and ecologic systems exist (Costanza et al., 1993), considering only one of these components would fail to cover all aspects of the mulitfunctionality of landscapes. Developing models to cover and evaluate the multiple landscape functions requires multidisciplinary cooperation.

To accomplish this goal, an interdisciplinary research centre at the University of Giessen develops an integrated methodology towards the realization and evaluation of economically and ecologically sustainable options for regional land use which are site-specific and economically differentiated. The main objective of this approach is to quantify economic, hydrologic and biodiversity indicators as measures of landscapes' multifunctionality. The approach includes the models ProLand, ANIMO, SWAT, and CHOICE. Figure 1 illustrates the model network and the data and information flow. The common objective of these models is to make predictions about the consequences of possible agricultural and environmental policy measures for the expression of landscape functions in rural areas. The landscape functions considered are the ability of a region to generate agricultural products, income from agriculture and groundwater, recreational value, biodiversity as well as compost recycling capacity. The model enables politicians to make informed judgements and decisions concerning regional policy.

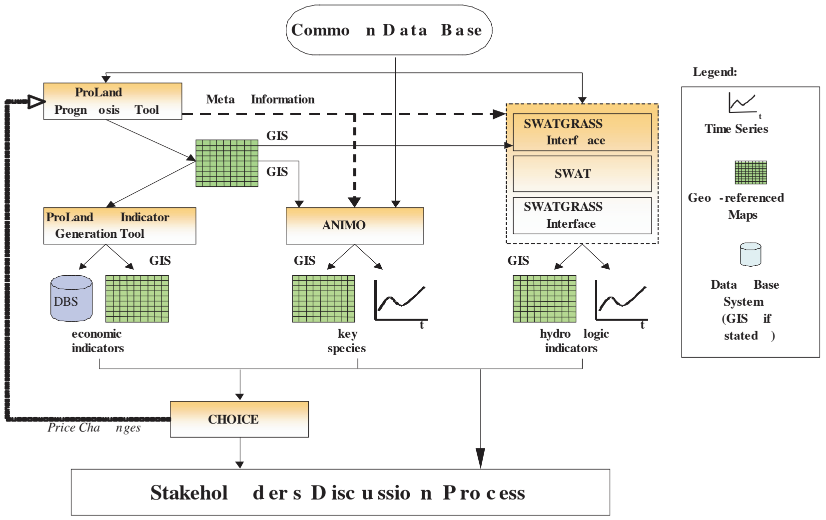


Figure 1. Data and information flow within the model family (according to Möller et al., 1999)

To accomplish this goal, an interdisciplinary research centre at the University of Giessen develops an integrated methodology towards the realization and evaluation of economically and ecologically sustainable options for regional land use which are site-specific and economically differentiated. The main objective of this approach is to quantify economic, hydrologic and biodiversity indicators as measures of landscapes' multifunctionality. The approach includes

the models ProLand, ANIMO, SWAT, and CHOICE. Figure 1 illustrates the model network and the data and information flow. The common objective of these models is to make predictions about the consequences of possible agricultural and environmental policy measures for the expression of landscape functions in rural areas. The landscape functions considered are the ability of a region to generate agricultural products, income from agriculture and groundwater, recreational value, biodiversity as well as compost recycling capacity. The model enables politicians to make informed judgements and decisions concerning regional policy.

The keynote of this modelling approach is to connect specialised models to quantify regional key indicators as basis for the multifunctional valuation of landscapes as shown in figure 1. Such a procedure has the advantage that specialised approaches can be used for each model without restrictions concerning the programming language. Sharing a common database and thus using the same data source for all models ensures trouble-free operation. A set of interfaces and calculation procedures for the models were defined in the database. For example, the data from the meteorological stations had to be processed for the models ProLand and SWAT. For this purpose, a definition of the calculation methods and the temporal resolution was necessary. For further technical details of the integration see Möller et al. (1999). A key component of the common database is the agreement on 25 m x 25 m as the raster grid's spatial resolution and a geographical information system as data exchange tool.

The model ProLand (Prognosis of Land Use) is at the centre of the evaluation process in this model network. ProLand is a comparative static model, and as the economical model, generates raster maps of land use distributions under various political conditions taking into account the given site specific physical conditions of the region (soil type, slope, temperature, precipitation, etc.). The model also estimates indicators (production volumes, employment, value added, etc.) describing the economic performance of the region (Möller and Kuhlmann, 1999). The raster maps generated by ProLand serve as input for the models ANIMO and SWAT and are exchanged using a common geographical information system.

ANIMO is a cellular automaton predicting changes in biodiversity due to changes in land use distributions. The land use scenarios generated by ProLand serve as matrix for simulation runs in ANIMO. The model assumes that each habitat type has a specific species inventory depending mainly on the type of land use. Changes of land use thus influence the biodiversity of the region. The hydrological model SWAT predicts the impact of changing land use patterns as well as of changing agricultural production management practices on water balance components. SWAT is a distributed continuous time model operating with daily time steps. It generates site-specific hydrological data (water, sediment, chemical yields, etc.), documented in raster maps of the region. For details see Weber et al. (2001).

Combining the results of the three models generates a set of key indicators describing the landscape's multifunctionality. In order to develop sustainable land use concepts it is crucial to determine the costs and benefits of different land uses. Cost-benefit analyses in the case of cultural landscapes have to include environmental goods like biodiversity, landscape aesthetics and water quality. Implementing the modelling framework CHOICE into this model network allows for such an extended cost-benefit analysis. CHOICE also provides ProLand with input data for the required price and policy information.

The next two sections focus on the model ProLand and the modelling framework CHOICE to give a deeper insight into the economic components of the described valuation process. Finally, an application is presented.

The model ProLand

In ProLand (**Pro**gnosis of **Land** use) it is assumed that the land use pattern is a function of the natural, economic, and social conditions. Changes of these conditions have an influence on land use. Based on small-scale information on the spatial distribution of physical, biological and socio-economic characteristics in a region, the allocation of land use systems is modelled.

To gain information on the ecological consequences of land use changes, cropland, pasture, forestry and abandoned land as an acceptable land use system is necessary. Urban areas, traffic areas and others are assumed as external constant and are not modelled. Pork, egg and poultry production is assumed to be spatially independent and therefore without effect on regional land use pattern.

The standard methodology to gain information on the potential spatial distribution of land use systems is to define an aggregate farm and to examine the production program using linear or nonlinear programming. Those approaches are methodological stringent, well established and have been continuously improved for many years (Henrichsmeyer, 1994, Bork et al., 1995, Moxey and White, 1998, Rounsevell et al., 1998, Dabbert et al., 1999). However, a major problem is to generate explicit position prognosis of future land uses, especially if landscapes of up to 1000 square kilometres with heterogeneous production conditions are modelled. Even if the data basis regarding farm characteristics and their geographical position is as good as in Denmark (Skop and Schou, 1999), the problem of assigning a particular area to a particular farm remains. The model approach presented here puts the spatial heterogeneity of the natural, economic and political framework of land use into the first place.

Therefore, two different types of model outputs have to be distinguished. First, a map of the potential spatial distribution of land use systems is generated. This map serves as input for the other models in the model network. Second, the model calculates a set of aggregated key indicators to characterise the economic performance of land use as results of specific scenarios.

The model can be employed as an economic laboratory, defining a variety of experiments by changing the input data. Trade-off functions regarding economic and basic ecologic variables are estimated from the generated output using the model network. These provide the basis for valuing land use options, and are therefore an important tool for political decision support.

Prior to the description of employed methods, the requirements for the modelling approach have to be clarified because of the strong influence on data input and calculation time. The model has to cover a region of approximately 1100 km^2, characterised by inhomogeneous natural conditions and widespread marginal agricultural land. For the purpose of methodological research and initial model testing the “Lahn-Dill-Bergland” in Hesse, Germany (see figure

4) was chosen. Modelling a region of this size requires a significant simplification in picturing the natural and economic situation. New approaches need to consider that it is impossible to gain primary information on the size, type, organisation, ownership and especially the location of agricultural land with a particular use and – at the same time – give a high resolution prognosis on regional land use. However, information on both, economic and ecological consequences requires a prognosis of the land use systems' distribution in a given region with a high spatial resolution.

The combination of a large region as a modelling object and the necessity of a high spatial resolution output requires some methodological peculiarities as described below. A grid of 25 m x 25 m as common basic unit guarantees a sufficient resolution for ecological and hydrological modelling. It is assumed that the land use of all areas other than urban, traffic and water can change. At current state, dynamic and stochastic elements of land use decisions are not implemented. ProLand is designed as a comparative static model approach, meaning its results have to be interpreted as valid "in the long run". Costs of adoption are not considered yet.

The model's basic behavioural function is maximisation of land rent. To measure the potential economic performance of land, the concept of land rent is an appropriate and useful approach (comp. van Kooten, 1993, p. 15ff). In ProLand it is assumed that the type of use of a particular piece of land depends on the achievable land rent. Accordingly the land use system with the highest land rent will be realised. In reality, farmers will employ a certain combination of the production factors land, labour and capital to maximise the farm income. However, the objective function in ProLand is the land rent. The basic hypothesis is therefore that farmers maximise the land rent ($LR_{max,pos}$) on condition that the factors labour and capital achieve a certain level, measured as realistic opportunity costs. It is calculated at a specific site (pos) as follows

$$LR_{\max,pos} := Max\left[\left(\frac{1}{n}\sum_{i=1}^{n} LR_{i,pos}\right), LR_{n+1,pos},\ldots,LR_{n+k,pos}, LR_{n+k+1,pos},\ldots,LR_{n+k+m,pos} \right]$$

$$\begin{aligned}
&with\\
&pos = \text{specific site}\\
&LR_{1,pos},\ldots,LR_{n,pos} = \text{Land rent of cash crops building different crop rotations}\\
&LR_{n+1,pos},\ldots,LR_{n+k,pos} = \text{Land rent of forest activities}\\
&LR_{n+k+1,pos},\ldots,LR_{n+k+m,pos} = \text{Land rent of grassland activities}. \qquad (1)
\end{aligned}$$

Equation 1. Objective function

Land rent in this context is defined as the sum of monetary yields including all subsidies minus input costs, depreciation, taxes as well as opportunity costs for employed capital and labour (Kuhlmann et al., 2002). The land user can select from a set of possible land use activities. They include, as stated in equation 1, a crop rotation ($LR_{1,pos}$,..., $LR_{n,pos}$) estimated by the model for every decision unit. In addition to that different types of forest ($LR_{n+1,pos}$,…, $LR_{n+k,pos}$) and grassland activities ($LR_{n+k+1,pos}$,…, $LR_{n+k+m,pos}$) are taken into account. The land rent is calculated for each according equation 2:

$$\begin{aligned} LR_{i,pos} &= R_{i,pos} - C_{i,pos} \\ &= \left(\sum_k c_{i,k}\, y_{i,pos} + \sum_l s_{i,l,pos} + \sum_m s_{i,m}\, y_{i,pos} \right) - \left(\left(\sum_n cy_{i,n}\, py_n \right) y_{i,pos} - \sum_p ca_{i,pos,p}\, ca_p \right) \end{aligned} \tag{2}$$

with

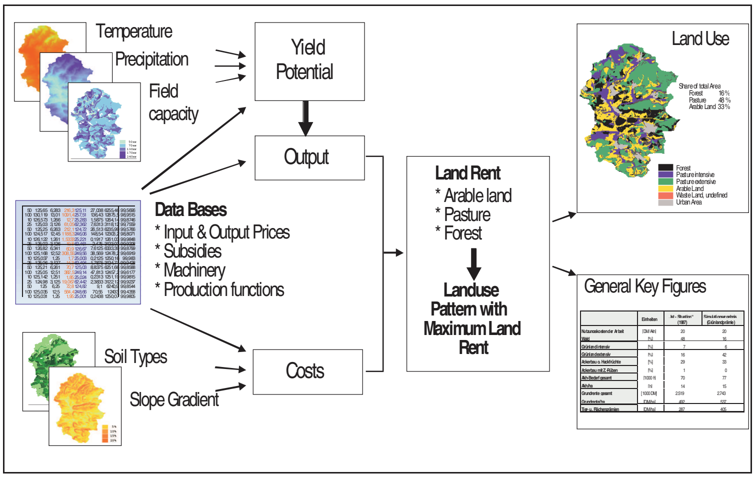
LR i,pos = the land rent (LR) for land use activity i at a specific site (pos) expressed in €/ha,
Ri,pos = the renvenue of land use activity i at a specific site (pos) expressed in €/ha,
C i,pos = the costs for land use activity i at a specific site (pos) expressed in €/ha,
ci,k = coefficient determining the monetary yield per unit for the k-th yield component of land use activity i expressed in €/dt,
yi,pos = the yield of the land use activity i at a specific site (pos) expressed in dt/ha,
si,l,pos = l-th subsidy depending on the specific site (pos) for the land use activity i expressed in €/ha,
si,m = m-th subsidy depending on the yield of land use activity i expressed in €/ha,
cyi,n = coefficient determining the amount per one unit of the yield depending production factor n of land use activity i expressed in quantity unit per yield unit,
pyn = costs of the yield dependent production factor n expressed in € per quantity unit,
cai,pos,p = coefficient determining the amount per one unit of area dependent production factor p of land use activity i at a specific site (pos) expressed in quantity units per hectare,
cap = costs of the area depending production factor p expressed in € per quantity unit.

The following explanation refers to a single decision unit (pos) but applies to all decision units' pos as the above equations are calculated for each unit. The revenue R_i of a production process i is the product of the expected yield y_i with the monetary yield per unit $c_{i,k}$ of the expected yield component. Thereon subsidies and premiums separated into decision unit depending $s_{i,l,pos}$ and yield depending components $s_{i,m}$ are added.

Production costs $C_{i,k}$ consist of yield and area dependent cost components. The yield dependent costs are the sum of the product's input-output coefficients $cy_{i,n}$ and the prices of the yield dependent production factors py_n multiplied with the expected yield. Pesticides and fertilizer mainly account for these costs.

The area dependent costs are equal to the sum of the products of the area dependent production factors' input-output coefficients $ca_{i,pos,p}$ and the area dependent production factor prices ca_p. They are mainly machinery and labour costs.

As shown in figure 2 the model estimates the land use with the highest land rent by taking into account physical features and calculating the yield potential of various possible crops. Of course, input and output prices, subsidies and production functions are needed in order to calculate revenues and costs of the various land use systems. This information is retrieved from an additional database. The following rationale determines the production functions for the various land use options:



	Einheiten	„Ist - Situation" (1987)	Simulationsergebnis (Grünlandprämie)
Nutzungskosten der Arbeit	[DM/Akh]	20	20
Wald	[%]	48	16
Grünland intensiv	[%]	7	6
Grünland extensiv	[%]	16	42
Ackerbau o. Hackfrüchte	[%]	29	33
Ackerbau mit Z.-Rüben	[%]	1	0
Akh-Bedarf gesamt	[1000 h]	70	77
Akh/ha	[h]	14	15
Grundrente gesamt	[1000 DM]	2.519	2.743
Grundrente/ha	[DM/ha]	492	537
Tier- u. Flächenprämien	[DM/ha]	287	405

Figure 2. Model Structure and Implementation of the Model ProLand

Crop output is the result of controllable as well as of non-controllable inputs. Controllable inputs comprise seed, fertilizer, plant protection products and services of workers and machinery. Non-controllable inputs comprise – under rain fed conditions – plant usable water, solar energy and the genetic yield potential of crop varieties.

Outputs and inputs – and that is the basic assumption – are connected via a linear-limitational production function, which is the familiar LEONTIEF-function, among crop scientists also called linear response and plateau function or v. LIEBIG response function, after its discoverer. This function states that crop yield levels are bounded by the limiting production factor (Kuhlmann and Frick, 1995).

Given functioning markets, i.e. land users are able to buy and apply all necessary controllable inputs, the crop yield levels are limited by at least one non-controllable input. Non-controllable inputs are spatially variant with respect to available amounts per land unit and quantitative relations between the non-controllable inputs.

Different crop varieties have different output-input-coefficients for non-controllable inputs. Thus, maximising income for the land user means growing different crops in different locations.

The approach used in ProLand is adapted to the models' common database. The spatial geo-referenced maps are in raster format with a resolution of 25 m x 25 m. ProLand estimates the land use for every raster unit using the following procedure. A single raster element is selected, and the land rent for every land use activity stored in the database is estimated. According to the behavioural function, the land use system resulting in the highest land rent is considered optimal and assigned to the element. This process is repeated for all raster units. ProLand thus generates a map showing the spatial allocation of land use systems and a set of economic key indicators describing the region's economic performance.

The modelling framework CHOICE

The methodological approach of CHOICE for the valuation of agriculture's multifuctionality is based on the well established tool of cost-benefit analysis. The purpose of traditional cost-benefit analysis is to gain information about the welfare effects of different alternatives in monetary and therefore comparable terms. In the case of agricultural production the benefits of the demand for agricultural and forestry products like food and wood have to be compared to the production costs of these products. In the case that domestic supply and demand are not in equilibrium the effects on trade have also to be taken into account. If more (less) goods are produced then demanded, the export revenues (import expenditures) enter as another benefit (cost) component as they allow for (prevent) alternative consumption possibilities. Additionally, the cost and benefit components of the private goods have to be extended by the components of the public goods (landscape functions). A deterioration of the environmental quality of the landscape will result in a cost component, amelioration in a benefit component. In this extended version cost-benefit analysis is useful tool for the evaluation of different land use concepts.

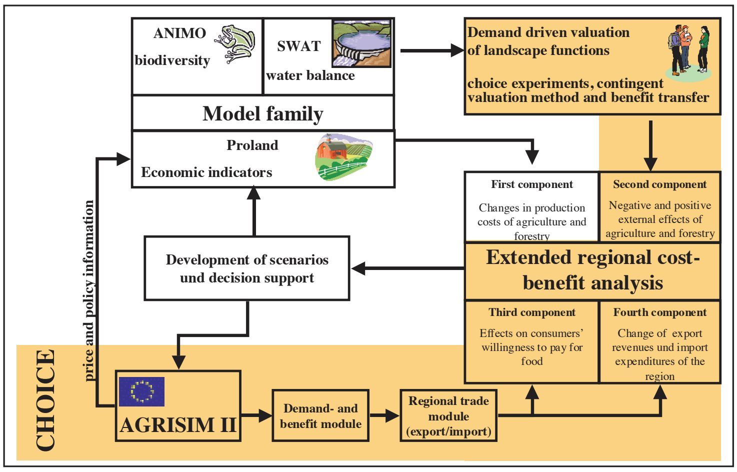


Figure 3. Implementation of CHOICE (elements shaded) into the model network of the SFB 299

The necessary step to provide an extended cost-benefit analysis is the implementation of the valuation framework CHOICE into the model network of ProLand, ANIMO and SWAT. As illustrated in figure 3 one task of CHOICE is to provide ProLand with the required information input on prices and policies. This allows the prices to become endogenous which is important for the simulation of major Common Agricultural Policy (CAP) reforms. Despite this service function CHOICE determines the three missing components of an extended cost-benefit analysis. Firstly, the welfare changes of the regional population due to the predicted changes in environmental goods are determined using modern valuation methods like contingent valuation and choice experiments (second component). Furthermore the implication of changes in agricultural and forestry production on demand (third component) and trade (fourth component) are calculated. These results and the production costs provided by ProLand (first component) allow to evaluate the modelling results in monetary terms. The following paragraphs present further information on the elements and functionality of CHOICE.

As illustrated in figure 3 the valuation framework CHOICE consists of four elements: the world trade model AGRISIM II, the methods of environmental valuation comprising benefit transfer, the regional demand and benefit module and lastly the regional trade module.

An important element is the simulation model AGRISIM II, which analyses and evaluates Agricultural and Trade Policies in an international context. It is a synthetic model with iso-elastic supply and demand functions, designed as a comparative static and deterministic multi commodity, multi region partial equilibrium model. It comprises 17 regions, nine agricultural products and is a further development of the original model AGRISIM (Schmitz, 2002; Pustovit, 2003). The model AGRISIM II calculates the price changes due to changing political or technical parameters, delivers the price information to the regional model ProLand and is therefore essential for the integrated valuation on a regional level. Shared variables like for example the subsidy level are defined consistently in both models. The major advantage of the application of AGRISIM II are the more reliable price information for ProLand, as they are generated in a sophisticated model taking into account supply, demand, trade and policy information. After exchanging the data with the model family, the four components of an extended cost-benefit analysis are determined as follows:

1. The relevant price and policy information are processed in the models ProLand, ANIMO and SWAT to quantify the cost and income effects for land users and the physical effects on landscape functions like biodiversity and water quality. As mentioned before the first component (the changed production costs as a result of political or technical innovations) can be taken directly from the output of ProLand.
2. The second component of positive and negative external effects of land use is determined through the application of modern demand-oriented valuation techniques. The objective is the revelation of the monetary value of environmental goods like biodiversity or cultural landscapes for the regional population. Stated preference methods like the contingent valuation method and choice experiments are used. The major advantage of stated preference methods is their flexibility and capability to also measure non-use values, which are especially important for

goods like biodiversity and landscape aesthetics (Müller et al., 2001; Schmitz et al., 2003). In order to draw conclusions for the whole region benefit transfer was used as a time and cost efficient transfer of value estimates to other geographic areas. In summary, the extensive valuation results for environmental goods allow the quantification of the important second component.

3. The third component is the benefit side of the food consumption (demand module). It addresses the changes in willingness to pay of the population in different scenarios. For this task a set of non-linear interdependent demand equations similar to the demand equations in AGRISIM II are defined for the region. These equations will be used to the quantity of food demanded at different price levels and relations and to estimate the benefit of food consumption.
4. Finally the fourth component consists of the changes in export revenues and import expenditures of the region, which are derived from the trade module. The trade module balances the results of supply (ProLand) and demand (demand module). The net trade quantities are multiplied with the relevant price changes and the trade surplus or deficit represents the last component of the extended cost-benefit analysis.

The results of the extended cost-benefit analysis can be used in two ways. On the one hand the results can be used for the development of more efficient instruments to reach economic and ecological objectives. The effectiveness of the new instruments can be tested by another run of the extended cost-benefit analysis. On the other hand the results can be used directly to assist political decision makers of the region.

Application of the model family and results

Study area and scenario description

The model ProLand is applied in a simulation example to the Aar watershed located in the central part of Hesse, Germany (compare figure 4). It is a disadvantaged low mountain region with poor natural conditions in terms of field capacity. Table 1 shows the Aar watershed characteristics.

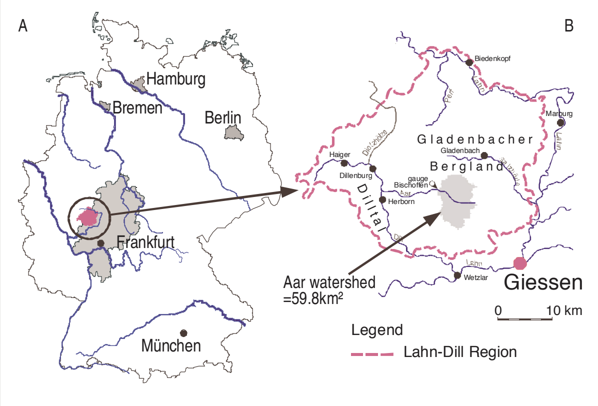


Figure 4. Location of the investigated region in Central Germany. (A) dark coloured the German state Hesse and the study area Lahn-Dill hill country. (B) dark coloured the Aar watershed test area.

The Aar watershed covers a total area of 60 km² with 335m average elevations above zero and 860 mm/a average precipitation. As seen in table 1 the share of plots having a low field capacity is almost 60%. The share of the land use systems with the model calibrated to satellite images recorded in 1994 reflects these natural conditions. More than 50% of the area is forest, whereas grassland takes a 24% share and a minor part of 20% is used for arable farming.

Table 1. Aar watershed characteristics

	Aar watershed
Total area [km²]	60
Agricultural and forestry land [ha]	5640
Elevation above zero [m]	
Range	257 – 478
Weighted average	335
Precipitation [mm/a]	
Range	780 – 1000
Weighted average	860
Area with "low field capacity" [%]	61

The focus of this paper is to investigate the effects of different production costs due to changing field size on the spatial distribution of land use systems, the corresponding regional key indicators and the trade-offs between economic, aesthetic and hydrological goals. In the public and scientific discussion field size is often used as an indicator of operating efficiency in agriculture by using large and high performance machinery and the ecological and esthetical situation of a landscape. Simplified, the average field size can be interpreted as a measure of a landscape's manifoldness.

To examine the effects of different field sizes on the land use distribution, the average field size was set to 0.5, 0.75, 1, 2, 5, 10; and 20 hectares. Because of the strong impact of the machinery configuration on the production costs, employed machinery was adapted to the technical potential of larger fields. A constant mechanization was assumed in forestry (8ha field size).

The GIS based model ProLand has been calibrated using a satellite scene (LandSat TM, classified by Nöhles, 1999). Setting the opportunity costs of labour at 9 € / hour and the average field size to 1 hectare, the model estimates the share of grassland and arable farming in the Aar watershed quite well, while it fits the forest acreage nearly perfect. A raster by raster comparison shows a correspondence of more than 60 percent in both regions.

ProLand, ANIMO, SWAT: regional key indicators and multi-objective trade-offs

The following figure 5 illustrates the spatial distribution of land use systems in this region depending on field size. In this region increasing field size means a decrease of forestry and an increase of grassland production systems. Using a scenario with 1 ha field size as reference, the Aar watershed region exhibits an increase in forestry up to 75% of total area as the field size decreases to 0,75 ha. The share of arable farming in the Aar it is reduced to a negligible part. Summarising, the Aar watershed is a region with strong changes in land use when changing the field size.

Note that ProLand simulation runs predict long term results without any regulations regarding land use changes. For this reason forest may be reduced and replaced by extensive grassland use. The simulations were also carried out with forest fixed to its current area share. An increase in field size shows the same tendential reaction.

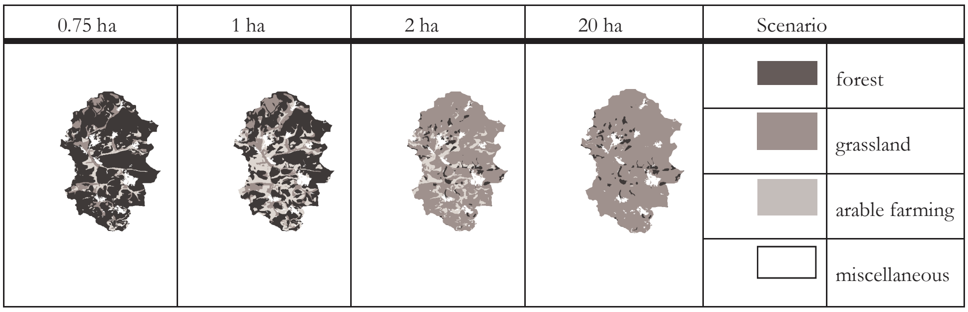


Figure 5. Spatial distribution of land use systems (Source: Own calculations with ProLand)

The model results are not only maps as in figure 5 but also quantified key indicators describing the economic performance of a region. Table 2 presents some of these indicators.

Note that the numbers in table 2 reflect the changes within the realised land use systems, the migration of production systems to other sites and finally the changing share of overall land use.

Table 2. Key indicators of Aar watershed

Aar watershed	Average field size [ha]							
	0.5	**0.75**	**1.0**	**1.5**	**2**	**5**	**10**	**20**
Forest [%]	84	75	54	34	5	5	5	5
Pasture (dairy) [%]	7	10	18	23	33	50	53	57
Pasture (sheep and suckling cows) [%]	0	0	0	18	42	35	34	32
Arable farming [%]	3	9	23	19	14	4	2	0
Settlement [%]	5	5	5	5	5	5	5	5
Added Value (Total) [Mio. €/Region]	1,9	2,2	3,0	3,5	4,5	5,2	5,3	5,4
Labour Input [1000 h]	86	104	140	168	212	223	226	225
Grain equivalents [1000 GE]	81	128	223	291	409	431	436	440

The grain equivalents as a measure of food production rise with increasing field size. Due to the land use change from forest to extensive grassland used by sheeps and suckler cows. As these land use systems need more labour, labour input also increases with increasing field size. Doubling the field size form 0.5 ha to 1 ha causes a huge rise in added value. Due to the rising share of agricultural land forestry is reduced by 30% in this case.

In addition to these results, so called “trade-off functions” were calculated within the model family because in most cases competitive relationships between some or all of the landscape functions exist. Figure 6 depicts this relation for the Aar watershed. The highest biodiversity (expressed as gamma diversity) is reached at a field size of 1.5 ha. A lower field size correlates with less labour input, less value added and less direct water flow. A larger field size results in reduced biodiversity while the other indicators increase.

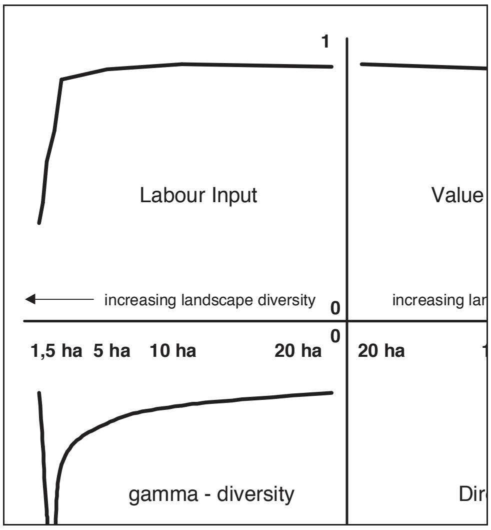


Figure 6. Multi-objective Trade-Offs for the Aar watershed (Source: Kuhlmann et al., 2003).

A noticeable change in landscape functions is only observable when changing the field size in the range of 0,5 to 5 ha. Increasing the field size above this margin results only in small changes of landscape functions.

Such multi-objective trade-offs can be employed as an evaluation tool, showing the consequences of action alternatives, putting politicians in a better position to make informed judgments and decisions concerning regional policy.

CHOICE: Economic valuation of environment and extended cost-benefit-analysis

The model family presented so far is limited to the effects on the supply side. That is, changes in the quality of ecological landscape functions can only be valued by the opportunity costs of agriculture or by the opportunity costs of changes in other landscape functions. Since the model family does not account for the demand side it is not yet possible to derive the real prices for the landscape functions and consequently it is impossible to reach the optimal allocation of resources and the optimal land use system. The valuation framework CHOICE is able to determine the monetary value of the change in environmental goods like biodiversity and landscape aesthetics using modern valuation techniques like the contingent valuation method and choice experiments. Thus, traditional cost-benefit-analysis can be extended by integrating these values.

The results of a Choice Experiment based on the results of ProLand, ANIMO and SWAT (see Schmitz et al., 2003) are used in this contribution. The most important and difficult stage in the design of choice experiments is the identification of the relevant attributes and attribute levels of the good to be valued. In applications of choice experiments to private goods in the field of marketing this is often a straight forward exercise, but a challenging task for public goods in environmental economics. Often the scientific fundamentals of the environmental goods are very complex and barely known. In this context the relevance of the attributes does not only comprise the underlying scientific aspects but also the definition of adequate indicators for their measurement. Even if the researcher manages to define the relevant attributes, levels and indicators of the environmental good according to best present knowledge, the cognitive limitations of respondents in empirical surveys have also to be kept in mind. The reduction of the scientific complexity while safeguarding the correctness of the simplification has top priority and requires the chosen interdisciplinary approach.

The model ProLand simulates the land use and one of its outputs are GIS-based maps of the distribution of grassland, arable land and forest. As the share of each land use is an important factor for the landscape aesthetics, artificial pictures with varying shares of each land use were included in the choice experiments as an approximation for this first landscape function. The incorporation of landscape aesthetics into the study design is supported by results of a former application of a conjoint analysis, which identified landscape aesthetics as an important element of sustainable land use systems (Müller, 2002).

The model ANIMO is able to quantify the effects of land use changes (given by the model ProLand via GIS maps) on the regional biodiversity. The regional biodiversity was also identified as an important element of a sustainable land use system by the former conjoint analysis (Müller, 2002) and was further stressed by the willingness to pay estimates from a contingent valuation method (Wronka, 2001). Of the three different biodiversity indices (α-, β- and γ-biodiversity) simulated in the model, the γ-biodiversity represents the biodiversity on a regional level and is best suited as an indicator. Nevertheless it was decided in discussion with natural scientists that the presentation of different levels of the γ-index of ANIMO is still too abstract for an empirical survey with the general public. For this reason the total number of selected indicator species were taken as an approximation for the regional biodiversity. The numbers of indicator species like ants, butterflies, bees, wasps, higher plants and birds had already been established by intensive surveys in the region. The last step was the assignment of the absolute numbers of species to the simulated results of the γ-biodiversity estimated by ANIMO. The range of the levels was chosen in such a way that it covers on the one hand the drastic decline in biodiversity due to the total withdrawal of agriculture from the region (forestation), and on the other hand the increase in biodiversity compared to the current situation. In total, five levels of biodiversity were selected with three levels between the two extreme cases.

The effects of agriculture on the hydrological situation are examined by the model SWAT. Several aspects are simulated in SWAT including the amount of groundwater recharge, the pollution of water with nitrates and phosphorous and the risk of flooding. The most important ecological element of a sustainable land use system is the drinking water quality as the results of the earlier valuation studies show (Müller, 2002; Wronka, 2001). Consequently, the quality of drinking water with regard to the pollution with nitrates was selected as a third attribute in the choice experiments. The range of the attribute levels includes the natural level of nitrate in groundwater (less than 10 mg nitrate/l) and a second level that keeps the nitrate content within the recommended guidance level (10-25 mg nitrate/l). The third level fulfils the legal requirement (25-50 mg nitrate/l) while the forth level exceeds it (50-75 mg nitrate/l). The fifth level has more than 75 mg nitrate/l water and is sometimes observed in intensive farming areas. The two other hydrological aspects were not included in the survey design as drinking water is not scarce in the region and the risk of flooding is not severe.

One of the more frequent arguments for the justification of subsidies for farming is food security and self-sufficiency. In order to investigate the importance of this aspect for a sustainable land use system, the degree of self sufficiency was included in the study as a fourth attribute. The extent of food production in the region under different land use systems was simulated in ProLand. Although it is simple for ProLand to calculate the amount of food production in the region (or as an aggregate the agricultural value added), the assignment of self-sufficiency levels is not easily determined. According to considerations of plausibility the range of the attribute levels was chosen from 60 % to 140 % degree of self-sufficiency.

Finally a price vector entered the study design to enable the estimation of implicit prices. The values were chosen reverting to the results of the contingent valuation method that were conducted three years ago.

The survey took place in three different geographical locations. Two villages were situated within the study area of the collaborative research project (Erda and Eibelshausen) and the third location was a city near the area under investigation (Giessen). The split sample design was intended to isolate differences in preferences of the population living within and outside the study area. A total of 216 interviews were completed in May and June 2002. The sample was drawn from all registered people in the locations aged between 18 to 80 years.

The implicit prices for all relevant attribute changes of the estimated model are shown in table 3. In this table negative signs indicate the average willingness to pay and positive signs indicate the average willingness to accept compensation. No implicit prices could be calculated for the medium level of drinking water quality and the highest level of self-sufficiency as those levels were not included in the final model and no coefficients were estimated.

Table 3. Implicit prices for changes in attributes (in € per household and year)

	Biodiversity (total number of species), base level				
	850	**690**	**530**	**370**	**210**
850	0.00	10.06	6.31	-13.48	-39.86
690	-10.06	0.00	-3.75	-23.54	-49.92
530	6.31	3.75	0.00	-19.79	-46.16
370	13.48	23.54	19.79	0.00	-26.37
210	39.86	49.92	46.16	26.37	0.00
	Landscape aesthetics (in % of forest)				
	5%	**35%**	**55%**	**75%**	**100%**
5%	0.00	11.23	11.73	3.89	-42.83
35%	-11.23	0.00	0.49	-7.34	-54.07
55%	-11.73	-0.49	0.00	-7.83	-54.56
75%	-3.89	7.34	7.83	0.00	-46.73
100%	42.83	54.07	54.56	46.73	0.00

	Drinking water quality (mg nitrate/l), base level				
	<10 mg	**10<x<25 mg**	**25<x<50 mg**	**50<x<75 mg**	**>75 mg**
<10 mg	0.00	12.68	-	-42.80	-62.37
10<x<25 mg	-12.68	0.00	-	-55.48	-75.04
25<x<50 mg	-	-	0.00	-	-
50<x<75 mg	42.80	55.48	-	0.00	-19.57
>75 mg	62.37	75.04	-	19.57	0.00

	Self sufficiency (in %), base level				
	140%	**120%**	**100%**	**80%**	**60%**
140%	0.00	-	-	-	-
120%	-	0.00	4.28	-3.37	-7.53
100%	-	-4.28	0.00	0.91	-11.81
80%	-	-3.37	0.91	0.00	-10.90
60%	-	7.53	11.81	10.90	0.00

Source: Schmitz et al., 2003.

The implicit prices in table 3 can be interpreted as follows: the different levels in the first row stand for the quality level of the attribute before the change (starting level). The resulting levels after the change are given in the first column. That means for example, that a change in biodiversity from 370 to 690 species results in an implicit price of -23.54 €. That is, the average individual is willing to pay this amount to achieve the higher level of biodiversity. In the case of the deterioration of biodiversity to the same extent as the above-mentioned improvement, the average individual would this time ask for exactly the same amount as compensation (23.54 €).

The following more general results can be concluded from a closer examination of the implicit prices in table 3. The relative importance of the attributes is reflected in the magnitude of the implicit prices. In particular, big changes over two or more levels in the attributes drinking water quality and biodiversity result in relatively high implicit prices. Changes in the attribute self-sufficiency on the other hand lead to only small implicit prices and this confirms the inferior importance of this attribute for the valuation of land use scenarios. With regard to the landscape aesthetics it can be noticed that only changes involving the situation with 100% forest result in high implicit prices. In all other cases the implicit prices are relatively low. It can be observed that the highest quality levels do not show the highest implicit prices. For more details see (Schmitz et al., 2003)

The final step leads to the extended cost-benefit analysis. The first component, the change of the production costs, is taken from the results of ProLand. The implicit prices shown in table 3 are used by CHOICE to derive the changes in welfare gains of the environmental goods as second component of the extended cost-benefit analysis. The relevant implicit prices per household are multiplied with the number of household in the study area. Supposing an average population density of 246 inhabitants per km^2 and an average household size of 2.14, about 6900 households are estimated in the examined area of ca. 60 km2. In the scenario of different field sizes only the landscape functions of biodiversity and landscape aesthetics are relevant for the second component because SWAT estimates only marginal differences of the quality of drink water. Self sufficiency was not taken into account. Regarding the third component, no changes of the examined scenario are due to the assumption of a "small region" with no price effects. Thus, consumption and the benefits of consumption are not influenced. Effects on import expenditure and/or export revenues serve as 4th component.

The results of the four components compared with the reference situation (forest only) are shown in table 4. Furthermore changes of direct payments are listed since they have a welfare-raising effect and influence the land use decision of ProLand as well considering direct payments without taking into account budget spending is justifiable for a region this size.

Table 4. Cost-benefit analysis of different field sizes (reference situation: forest only)

Change (in 1000 €)	**Average field size**							
in...	**0.5 ha**	**0.75 ha**	**1 ha**	**1.5 ha**	**2 ha**	**5 ha**	**10 ha**	**20 ha**
...benefits of consumption	0	0	0	0	0	0	0	0
...costs	1450	1997	3249	4047	5420	6367	6613	6806
...trade balance	1489	2006	3267	3974	5310	6803	7105	7402
...amount of direct payments	32	115	285	493	770	497	448	388
...benefits of use of landscape functions	322	641	721	648	614	477	296	296
...total welfare	**393**	**765**	**1024**	**1068**	**1273**	**1411**	**1237**	**1279**

Source: results of ProLand and own calculations.

As mentioned above the benefit of the consumption of goods does not change. Compared to a forestry use the production costs rise with increasing field-size with just marginal changes from 5 ha on. The absolute value trade balance shifts in the in the same way. The positive signs denote that the import costs fall and the export gains rise. Compared with the reference situation the biggest raise of the benefits is found at an average field size of 5ha. The direct payments rise opposite to the forestry use up to a field size of 2 ha and reach there maximum at this point. The forestry share reaches its minimum (5%) and nearly the whole area is qualified to get higher prices from agricultural production. At large fields the share of acres declines compared with the share of grassland. This leads to a declining sum of direct payments because of the smaller direct payments for grassland. Compared with the reference situation the extension of the fields and the beginning of agricultural land use the situation improves concerning the landscape functions biodiversity and landscape. This leads to a_benefit at all field-extensions because an open landscape is always preferred to forest. With the Extension of the fields the biodiversity is declining again and so the welfare benefits are declining at field sizes from 2 ha on as well. The biggest welfare benefits for landscape functions are achieved at field sizes from 1 ha on. These changes of welfare are shown in figure 7. Here the effects of costs, the trade balance and the direct payments are aggregated as market-goods and compared with the effects trough landscape functions.

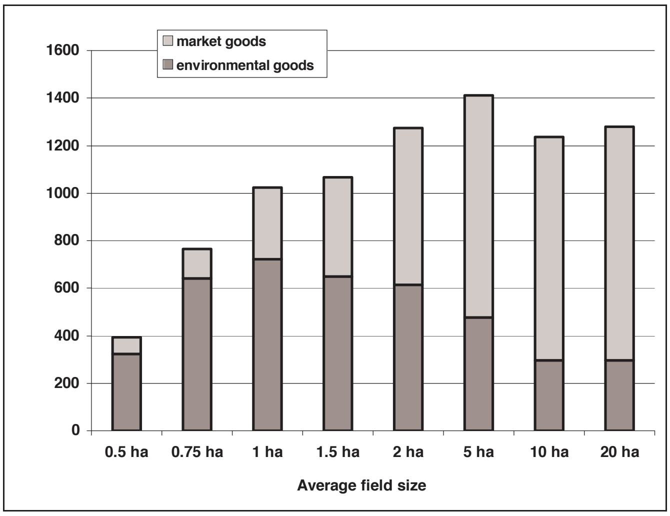


Figure 7. Change in welfare assuming different field sizes in the Aar watershed (reference situation: forest only) (Source: results of ProLand and own calculations)

The results in figure 7 clearly show the importance of environmental goods for the society. As was theoretically expected, the welfare gains from market goods are constantly rising with increasing in average field size, reaching their maximum at 20 ha. In comparison the welfare gains of the environmental goods are higher for the smaller field sizes. They show a maximum at 1 ha and then decrease due to the loss in biodiversity. Taking both effects into account the maximum welfare gain is realised in the 5 ha scenario. This demonstrates the value of environmental goods like biodiversity. Ignoring these values could result in a welfare loss for society.

Summary

The current public and political discussion concerning multifunctionality of landscapes calls for decision support systems, showing the consequences of different courses of action. The main target group are politicians, because they can influence and decide about future development trends. An approach to provide such a tool is presented combining specialised models to evaluate landscapes with the aid of a set of indicators. The models are connected via a common database and a set of interfaces. The model ProLand as an economic model produces two results. First, a map showing the spatial allocation of land use systems, which is a major input for the ecological and hydrological models. Second, a set of economic indicators describing the economic performance of the simulated land use. The model ANIMO as a cellular automaton predicts the changes in biodiversity connected to the simulated land use. The third model SWAT as the hydrological model predicts the impact of changing land use patterns as well as of changing agricultural production management practices on water balance components. The combination of the predicted indicators describes the landscape's multifunctional functions. Trade-off functions between different landscape functions illustrate the complex interactions between the parameters. The valuation framework CHOICE integrates the results of this network of independent models from different disciplines. Using valuation techniques like the contingent valuation method and choice experiments, it is possible to explicitly consider the effect of the simulated land use changes on the welfare of the regional population. This leads to an extended cost-benefit-analysis and hence enables the supply and demand based valuation of multi-functional agriculture.

References

Bockstael N.E. (1996): "Modelling Economics and Ecology: The Importance of a spatial perspective", *American Journal of Agricultural Economics*, 78: 1168-1180.

Bork H.-R., Dalchow C., Kächele H., Piorr H. and Wenkel K.O. (1995): *Agrarlandschaftswandel in Nordost-Deutschland*, Verlag Ernst & Sohn, Berlin.

Costanza R., Wainger L., Folke C. and Mäler K.-G. (1993): "Modeling Complex Ecological Economic Systems", *BioScience*, 43 (8): 545-555.

Dabbert S., Hermann S., Kaule G. and Sommer M. (eds.) (1999): *Landschaftsmodellierung für die Umweltplanung*, Berlin, Heidelberg.

Henrichsmeyer W. (1994): "Räumliche Verteilung der Agrarproduktion", *Agrarwirtschaft*, 43: 183-188.

Kuhlmann F. and Frick P. (1995): "Das Ertragsgesetz und das Minimumgesetz: Eine produktionstheoretische Analyse", *Bericht über Landwirtschaft*, 73: 591-623.

Kuhlmann F., Möller D. and Weinmann B. (2002): "Modellierung der Landnutzung: Regionshöfe oder Raster-Landschaft?", *Berichte über Landwirtschaft*, 80 (3): 351-392.

Kuhlmann F., Weinmann B. and Sheridan P. (2003): "Supply Oriented Valuation of Land Use Systems Combining Economical, Ecological and Hydrological Models", in Kissling M., Schmitz K., Schmitz P.M. and Wronka T.C. (eds.), *Pricing Environmental Services of Agriculture*, Wissenschaftsverlag Vauk Kiel KG: 117-130.

Kooten G.C. van (1993): *Land resource economics and sustainable development – Economic policies and the common good*, UBC Press, Vancouver.

Möller D. and Kuhlmann F. (1999): *ProLand: A New Approach to Generate and Evaluate Land Use Options*, IX European Congress of Agricultural Economists, Warsaw, Poland.

Möller D., Fohrer N. and Weber A. (1999): "Methodological Aspects of Integrated Modelling in Land Use Planning", in Schiefer G. et al. (eds.): *Perspectives of Modern Information and Communication Systems in Agriculture, Food Production and Environmental Control*, Vol. A: 109-118, Bonn, Germany.

Moxey A. and White B. (1998): "Interdisciplinary Modelling of Agri-environmental Problems: Lessons from NELUP", in Dabbert et al. (eds.): *The Economics of Landscape and Wildlife Conservation*, CAB International: 231-238.

Müller M., Thiele H., Schmitz P.M. and Wronka T.C. (2001): "Integrierte ökonomische und ökologische Bewertung der Landnutzung in peripheren Regionen", in *Berichte über Landwirtschaft*, 79, Heft 1: 19-48.

Müller M. (2002): *Präferenzen und Zahlungsbereitschaften für ausgewählte Landschaftsfunktionen*, Kiel, Wissenschaftsverlag Vauk Kiel KG.

Nöhles I. (1999): *Landnutzungsklassifikation mit multitemporalen LandSat-TM-Szenen unter besonderer Berücksichtigung von Sukkzessionsbracheflächen*, Diss. in preparation, Dept. of Agricultural Ecology and Natural Resources Management, Univ. Giessen, Germany.

Pustovit N. (2003): *EU-Osterweiterung und WTO-Liberalisierung aus Sicht der ukrainischen Agrarwirtschaft – Wirkungsanalyse und Bewertung mit Hilfe eines partiellen Gleichgewichtsmodells*, Agrarökonomische Monographien und Sammelwerke, Wissenschaftsverlag Vauk Kiel KG, Kiel.

Rounsevell M. et al. (1998): "The IMPEL project: integrating biophysical and socioeconomic models to study land use change in Europe", *Proceedings of the World Congress of Soil Science*, Montpellier, Aug. 1998.

Schmitz K. (2002): "Simulationsmodell für die Weltagrarmärkte – Modellbeschreibung", in Schmitz P. M., *Nutzen-Kosten-Analyse Pflanzenschutz*, Wissenschaftsverlag Vauk, Kiel: 117-137.

Schmitz K., Schmitz P.M. and Wronka T.C. (2003): "Integrated Ecological and Economical Valuation of Land Use Systems", in Kissling M., Schmitz K., Schmitz P.M., Wronka T.C. (eds.): *Pricing Environmental Services of Agriculture*, Wissenschaftsverlag Vauk, Kiel KG: 131-152.

Skop E. and Schou J.S. (1999): "Modelling the effects of agricultural production. An integrated economic and environmental analysis using farm account statistics and GIS", *Ecological Economics*, 29 (1999): 427-442.

Weber A., Fohrer N. and Möller D. (2001): "Long-term land use changes in a mesoscale watershed due to socio-economic factors – effects on landscape structures and functions", *Ecological Modelling*, 140: 125-140.

Wronka T.C. (2001): "Biodiversity and drinking water quality: an analysis of values and determinants of willingness to pay", in Peters G.H. and Pingali P. (eds.): *Tomorrow's Agriculture: Incentives, Institutions, Infrastructure and Innovations*, Proceedings of the 24th International Conference of Agricultural Economists, Ashgate: 784-785.