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Research, part of a Special Feature on Landscape Scenarios and Multifunctionality – Making Land Use Assessment Operational

Evaluating Today's Landscape Multifunctionality and Providing an Alternative Future: A Normative Scenario Approach

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ABSTRACT. Intensive agriculture has had multiple negative effects on the environment across large areas of Europe, including a decrease in the degree to which these landscapes serve multiple functions. A quantitative evaluation of the deficits in landscape multifunctionality is difficult, however, for a given landscape as long as "multifunctional reference landscapes" are lacking. We present an interdisciplinary normative scenario approach to overcome this obstacle. Given the example of the lower Wetter-catchment in the Wetterau region (Hesse, Germany), we compare the existing landscape with an expert-generated multifunctional landscape scenario that may also serve as an alternative future. This approach may inspire policy makers and land users by providing a methodology for the design of alternative multifunctional futures in five steps: (1) documentation of today's landscape structure and land use at the scale of uniformly managed land units; (2) detection of functional deficits of today's landscape considering environmental (soil contamination, groundwater production, water quality, biodiversity), economic (land rent), and societal (landscape perception by its population) attributes; (3) compilation of a catalogue of alternative land uses (including linear landscape elements) suitable to minimize the detected functional deficits; (4) rule-based modification of today's land-use pattern into a normative scenario; and (5) comparison of today's landscape and the normative scenario by applying the model network ITE^{2}M. Results highlight a strongly unbalanced allocation of private and public goods in today's landscape with severe deficits in environmental and societal landscape features, but a significantly higher land rent. The designed multifunctional scenario, instead, may be preferred by the local population, and their willingness to pay for multifunctionality could potentially compensate calculated opportunity costs. Hence, the generated landscape scenario may be regarded as an alternative, multifunctional future.

Key Words: *agriculture; ecosystem services; Germany; modeling; sustainability*

INTRODUCTION

For thousands of years, farmers have not only produced food and fiber (private goods), but have also affected multiple ecosystem functions, such as biodiversity, water, and soil quality, or provided cultural identity (public goods). However, most agricultural landscapes have not met all the complex and sometimes contradicting requirements and expectations of society (Helming and Wiggering 2003), neither in the past nor today. This holds especially true for highly productive regions that are dominated by either intensive dairy production or cash crop farming. There, high value-added production goes hand in hand with well-known ecosystem changes, such as biodiversity loss (Benton et al. 2003, Donald et al. 2006, Billeter et al. 2008), that result from eutrophication, pesticide

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use, low habitat diversity and quality, and altered landscape structure. Moreover, such landscapes barely provide recreational, cultural, and esthetic experiences (Dramstad et al. 2001, Gobster et al. 2007), which are particularly needed in highly urbanized societies.

The concept of multifunctionality in agriculture, which was drafted at the Rio Earth Summit of 1992 (UNCED 1992), is a valuable conceptual framework, within which landscape ecology can address the imbalances in the allocation of private and public goods in agricultural landscapes (cf. Mander et al. 2007). Multifunctionality may be described in terms of optimal land allocation: "agricultural land is optimally allocated if it fulfills the mixture of functions demanded by society" (Jongeneel et al. 2008). Aside from the concept of multifunctionality, the concepts of sustainable development and ecosystem services have also been used to help define relationships between society and nature. Sustainable development refers to the vulnerability of ecosystems and the need for conserving resources to ensure long-term delivery of ecosystem functions. According to the World Commission on Environment and Development, sustainable development "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Sustainability is generally understood to include the dimensions of ecological, economic, and societal perspectives. Ecosystem services are defined as the benefits people obtain from ecosystems (MA 2003) and directly address ecological, economic, and societal functions.

Based on the premise that the global demand for multifunctionality, sustainability, and ecosystem services will substantially increase in the future (Alcamo et al. 2005, Huber et al. 2007), and that agriculture has dramatically increased its ecological footprint (Butler et al. 2007), alternative pathways toward multifunctionality and sustainable development, such as a sound implementation of agri-environment schemes at the landscape scale (Herzog 2005), are urgently needed. In the European Union, multifunctionality of agriculture has become the key concept or a new paradigm for agriculture and rural development (Tait 2001, Van Huylenbroeck and Durand 2004). With a wide array of conceptualizations, agricultural multifunctionality has also attracted attention in other parts of the world (e.g., Anderson 2000, Bills and Gross 2005, Cocklin et al. 2006, and cf. Wilson 2007). Thus, policy needs to cope with the challenges of trade-offs between the three dimensions of landscape functions (and services) and even between different measures within one of these dimensions, if the vision of multifunctionality is to be translated into reality at the landscape scale. In general, this challenge requires inter- and multidisciplinary work, and during the last decade, many researchers have undertaken efforts in developing scientifically sound approaches (e.g., Wiggering et al. 2006, Gimona and van der Horst 2007, Groot et al. 2007, Parra-López et al. 2008) to promote the implementation of multifunctional land use at the landscape scale.

Such approaches need to consider two main research components: (1) the evaluation of the status quo of landscape multifunctionality (ex-post evaluation) or of scenarios of future land use (ex-ante evaluation) that might become reality under certain societal and political developments and decisions (e.g., Sharma et al. 2006, Sheate et al. 2008), and (2) the design of alternative futures "that portray futures that should be" (Nassauer and Corry 2004). In both research components, three main challenges must be addressed: the need for inter- and transdisciplinary approaches and tools that cover the three dimensions of landscape functions (e.g., Mattison and Norris 2005, Groot et al. 2007, Rossing et al. 2007), consideration of scales (e.g., Dunford and Freemark 2004, Rodríguez et al. 2006), and the need to develop spatially transferable approaches.

Against this background, our interdisciplinary research group developed an integrated, five-step, indicator-based approach to evaluate the multifunctionality of intensively used agricultural landscapes and applied this approach to a highly productive agricultural landscape in Germany. As a reference landscape for the evaluation of today's land use, we designed a normative multifunctional landscape scenario (MS). Based on a set of ecological and economic indicators derived from spatially explicit, high-resolution landscape models, we compare today's land use, represented in a base scenario (BS), with the MS. The selected ecological indicators relate to soil quality, water, and biodiversity and thus cover the main environmental landscape functions that may be impaired in intensively used agricultural landscapes. The selected economic indicators provide a deepened insight into the regional value added and transfer payments. Moreover, we evaluated the people's perception of both today's and the designed landscape and estimated the willingness of the local population to pay for multifunctional agriculture.

This paper presents the methodological steps of the approach, gives an example of the application of this approach, and discusses the interdisciplinary methodology, its limitations, and usefulness for decision makers and farmers.

STUDY REGION

The lower Wetter-catchment (166 km²), located in the Wetterau region in the German Federal State of Hesse, was selected as the study region. In the larger area of the Wetterau at altitudes between 120 and 250 m above sea level, fertile and well-drained luvisols are predominant (outside of the alluvial plains of small rivers). Mean annual temperature is 9°C, duration of the growing season (number of days with an average daily temperature > 5°C) is 240 days, and average annual precipitation is about 600 mm.

The Wetterau has been populated since Paleolithic times, and cultivation of arable land, which is still typical of the scenery today (about 40% of the entire area and about 70% of the agricultural land), dates back five thousand years. In the recent past, crops were cultivated on small fields with mean field size below 1 ha, as delineated from air photos dating back to 1950. The landscape scenery included a pronounced network of farm tracks and traditional apple orchards in close proximity to the settlements. Today, large portions of the former apple orchards are either lost due to residential development or under cultivation. Moreover, field sizes increased significantly as a result of land consolidation (present day mean field size is about 2.0 ha, which is comparatively large for Hesse). Wheat, barley, rapeseed, maize, and sugar beet are the most important crops in short crop rotations. In general, today's agricultural land use intensity is high with respect to fertilization and pesticide application.

Today, the agricultural land of the Wetterau is considered an area that does not provide much space for biodiversity. Population sizes and occurrence frequencies of formerly common wildlife species, such as the common hamster (*Cricetus cricetus*), have dramatically decreased. Moreover, abiotic resources have been negatively impacted by agricultural practices, including high nitrate concentrations in rivers, heavy metal enrichment in arable soils from the use of sewage sludge, and soil water erosion on arable land. Finally, due to the predominance of arable fields and short crop rotations, today's landscape scenery is monotonous and less attractive for recreation and tourism in large parts of the region. Thus, the study region is characterized by a suboptimal allocation of private and public goods and may not fulfill the requirements of landscape multifunctionality.

METHODOLOGY: FIVE-STEP APPROACH

To evaluate today's landscape multifunctionality, we developed a five-step approach. We compare a generalized view of today's landscape (BS) with an expert-generated multifunctional landscape scenario (MS) that aims to meet the requirements of multifunctionality. This expert-generated alternative future is meant to be considered by policy makers and farmers as one possible solution to today's environmental and societal deficits in land use. In general, our approach is applicable not only to the region under study, but to all intensively used agricultural landscapes, provided that the required input data are available.

Step 1: Documentation of today's landscape structure and land use at the scale of uniformly managed land units (designing of the BS)

We used digital information at the scale of uniformly managed land units (patch scale) on land-cover classes such as arable land or grassland derived from air photo interpretation (conducted by EFTAS Remote Sensing Transfer of Technology GmbH, Münster, Germany), soil types (digital soil map 1:50,000), and topography (digital elevation model; resolution 20 m), provided by the Hessian State Agency for Environment and Geology. Further, we defined site-specific agricultural production systems (based on field expertise and agricultural statistics) to document today's landscape structure and land use. Data were stored in Microsoft Access databases and linked to ArcGIS 9.1 to allow for visualization. Overlay analysis of different thematic layers resulted in a generalized view of today's landscape (BS).

Step 2: Detection of functional deficits of today's landscape

Designing a normative future requires expertise of the landscape under study and, moreover, of agricultural production systems and their potential effects on landscape functions. Members of all participating research groups of the Agricultural Faculty of Giessen University have been familiar with the study region for several years. Even prior to our study, environmental problems (e.g., low biodiversity at the patch scale) resulting from agriculture were obvious in the Wetterau region. However, detailed data needed for a qualified detection of functional deficits were initially unavailable. As these were also essential for indicator-based modeling, we conducted empirical research (e.g., water chemical analyses and vegetation surveys) and additionally evaluated regional agricultural statistics to broaden and deepen our expertise on today's functional deficits related to landscape structure and agricultural land use.

Step 3: Compilation of a catalogue of alternative land uses (including linear landscape elements)

Informed by the data compiled in Steps 1 and 2, and cognizant of the obligations affecting agricultural land use in Germany and the EU (e.g., Water Framework Directive, Nitrate Directive, Soil Protection Act, Nature Conservation Act, Agri-Environment Schemes), each participating group evaluated from its disciplinary view the potential of certain measures or land use systems (e.g., measures contemplated in agri-environment schemes [HIAP: Hessian Integrated Agri-Environment Scheme; HMULV 2007], reduced soil tillage, or organic production systems) to enhance or impair the respective environmental landscape functions (chemical soil quality, hydrology, floristic diversity, faunistic diversity). Given a multitude of potentially suitable agricultural practices (cf., e.g., Herzog 2005, Marshall et al. 2006), this step resulted in a list of disciplinary ideas that were compiled in a catalogue of alternative land uses.

Step 4: Rule-based modification of today's land use pattern into a normative scenario

Based on this catalogue, we determined rules for the spatially explicit incorporation of these alternative land uses in the MS. Through extensive interdisciplinary discussions, we found balanced compromises among conflicting goals related to the landscape functions under consideration. We did not aim to design an entirely new landscape, but to find a science-based pragmatic approach toward a balance of productive and nonproductive functions at the landscape scale. With the help of standard ArcGIS techniques, the rules were used to modify the BS and hence to create a landscape model of the MS.

Step 5: Comparison of today's landscape and the normative scenario

To evaluate the degree of landscape multifunctionality of the BS against the MS, we applied the indicator-based model network ITE²M, which was originally developed as an integrated tool for the development and evaluation of economically and ecologically sustainable options for regional land use (Frede and Bach 2002, Waldhardt 2007, Schaldach and Priess 2008). Previous applications of the ITE²M models concentrated on the evaluation of land use scenarios that might become reality for certain developments in the European Common Agricultural Policy (CAP). Details on the underlying theories and concepts, methodologies and limitations, and disciplinary and interdisciplinary results have been published elsewhere (see Table 1). They will thus not be presented here in detail, but are briefly outlined below. In this study, the ITE²M modeling focused on a set of indicators (Table 1) that were selected based on the results gained in Step 2.

For both scenarios, the GIS-based ITE²M models ATOMIS, SWAT, ProF, GEPARD, and ProLand calculated indicator values (I) related to spatial units ranging from 100 m² up to 25 ha (Table 1). These reference units reflect the different spatial scales that, in previous studies, were found to be appropriate for each indicator. To evaluate the BS at the scale of the reference units, we calculated the differences of each indicator value (ΔI) between the BS and the MS:

Table 1. The model network ITE²M with its indicators, spatial reference units, and model output considered in this study. All models, with the exception of SWAT (Arnold et al. 1998), were developed in the research groups contributing to this study.

Acronym	Name	Selected publications	Indicators considered in this study	Spatial reference unit	Model output
ATOMIS	Assessment Tool for Metals in Soils	Breuer et al. 2007, Reiher 2008	Cu, Zn, and Cd input loads and topsoil concentrations	20 × 20 m	Means per ha
SWAT	Soil and Water Assessment Tool	Fohrer et al. 2005, Breuer et al. 2007	Nitrate-N loads, discharge, evapotranspiration	100 × 100 m	Means per ha and year
ProF	Prognosis of Floristics	Waldhardt et al. 2004, Sheridan and Waldhardt 2006	Plant species richness, richness in insect-pollinated species, and low-nutrient indicators	500 × 500 m	Means per 25 ha
GEPARD	Geographically Explicit Prediction of Animal Richness Distributions	Gottschalk et al. 2007, 2009, 2010	Breeding populations of nine indicator bird species	10 × 10 m	Means per 100 m²
ProLand	Prognosis of Land Use	Möller 1998, Möller et al. 2002, Weinmann 2002, Weinmann et al. 2006, Sheridan and Waldhardt 2006, Sheridan et al. 2007	Land rent, transfer payments, recommendation on N-fertilization	Land parcel	Means per ha and year
CHOICE	Choice Valuation of Non-Commodities	Schmitz et al. 2003, Borresch et al. 2005, Schmitz 2008	Willingness to pay for landscape scenery	Landscape	Willingness to pay per household and year

$$\Delta I = I_{BS} - I_{MS} \qquad (1)$$

To allow for an integrated ecological–economic evaluation of today's multifunctionality at the scale of the entire study region, we aggregated the spatially explicit indicator values by calculating mean indicator values ($\bar{I}$) for both BS and MS, and the BS was evaluated against the MS as follows:

$$\bar{I}_{BS} / \bar{I}_{MS} \times 100\% \qquad (2)$$

Our comparison of the BS and the MS also included the people's perception of landscape scenery. In this regard, we applied the CHOICE modeling and assessment framework by means of a comprehensive cost-benefit analysis and the calculation of the willingness of the local people to pay for the landscape scenery under both landscape scenarios. The CHOICE modeling also estimated the consumer surplus per household resulting from a change from BS to MS, and we related this consumer surplus to the respective opportunity costs calculated in ProLand.

In the following paragraphs, we give some outline information on the ITE²M models and their application in this study.

ATOMIS:
The model ATOMIS calculates the potential accumulation of heavy metals for each agriculturally managed patch depending on deposition and fertilizers (organic and conventional pig slurry and cattle manure, sewage sludge, mineral NPK-fertilizer [applied to conventional managed sites], and rock phosphate [applied to organic fields]). Calculations are based on site-specific pedotransfer functions and thus reflect soil sorption characteristics. In this study, the amount of applied farmyard manure was determined by the P-demand (in the model network, this information is provided by ProLand), whereas its composition was in accordance with today's regional livestock density. Moreover, in this study, modeling of heavy metal accumulation was calculated over a period of 100 years.

SWAT:
Modeling of water quality and quantity in the widely established SWAT model refers to nine subcatchments of the study region, delineated with the help of a digital elevation model (cf. Step 1). Subcatchments are further subdivided into hydrological response units (HRU) considering data on production systems (e.g., amount of N-fertilization; in the model network, this information is provided by ProLand) and soil quality. On the level of the HRU, the model calculates the hydrological as well as the nutrient balance on a daily time step. In this study, for both scenarios, the simulation period was 1990–2002, and the first five years were used as a warm-up phase to reach equilibrium in the model's water and nutrient storage.

ProF:
Modeling of plant species richness in ProF is based on the simplifying assumption of a binomial distribution of plant species within the patches of predefined habitat types. ProF uses the probability of plant species occurrence in habitat types, and the respective number of habitat patches, to estimate the species richness of complex habitat patterns of a given discretionary size (in this study, 25 ha). The definition of habitat types for this study was restricted to agricultural land. For the BS, we considered the habitat types (1) grassland (on dry, moderate, and wet soils), (2) fruit orchards (on either acidic or base-rich soils), and (3) arable land (classified as winter wheat, winter and summer barley, rape seed, corn, potato, sugar beet fields). For the MS, reflecting the incorporation of alternative land uses (cf. Table 2), we additionally defined (4) extensively managed grassland types on moderate and wet soils, (5) extensively managed perennial field margins, (6) organic fields, (7) wild flower fields, and (8) extensively managed (annual) field margins for each crop. The occurrence probabilities in habitat groups 1–5 were derived from their respective frequency in field data (30 species lists per habitat type; field studies conducted in 2006 and 2007 as part of Step 2). For habitats only stated in the MF (groups 6–8), we used the same species lists but employed expert knowledge to adjust the expected higher probabilities of occurrence in these habitat types.

GEPARD:
In this study, the breeding populations of nine farmland indicator bird species (SISD, Stickroth et al. 2004) were modeled. For seven species, we used resource-selection functions based on species' distributions and land use information (maps of the BS and the MS). Abundances for Skylark (*Alauda arvensis*) and Yellowhammer (*Emberiza citronella*) were required in 300 five-minute Point Counts using Distance Sampling (Buckland et al. 2001) (field studies in 2006 and 2007 as part of Step 2). Presences of Little Owl (*Athene noctua*), Lapwing (*Vanellus vanellus*), and Corn Bunting (*Miliaria calandra*) (HGON 2005, *unpublished data*) as well as Red Kite (*Milvus milvus*) and Red-backed Shrike (*Lanius collurio*) (HGON 1998, *unpublished data*) were based on 400 available nest records. Twenty land use and topographical variables entered the generalized linear models (GLM) while establishing resource-selection functions using GEPARD. Estimated occurrence probabilities per pixel for rare species were translated into abundances by multiplying them with literature-based breeding densities (Bauer et al. 2005). Because Black-tailed Godwit (*Limosa limosa*) and Whinchat (*Saxicola rubetra*) were absent in today's landscape, existing knowledge on their habitat requirements was used to predict their breeding-population sizes in the MS rather than resource-selection functions.

Table 2. Aggregated list of alternative land uses (including linear landscape elements), rules for their incorporation in the MS, and main goals.

Alternative land uses	Rules	Main goals
Land parcels		
Field aggregation	Aggregation of fields with >4% slope to units with >100 m width to facilitate cultivation in slope-parallel direction	Reduce variable costs; reduce soil erosion
Organic farming	Conversion from conventional to organic farming; reduced tillage; about 15% of today's arable land	Reduce fertilizer input; provide habitats for a rich arable vegetation and fauna; reduce the risk of N-input in water
Flowering fields	Sowing of flowering vegetation on arable land in accordance with HIAP[†]; random selection from fields <2 ha; about 3% of today's arable land	Reduce fertilizer input; provide habitats for fauna; protect the soils
Grassland, extensive I	Extensive grassland use in accordance with HIAP (e.g., without fertilization, mown once or twice a year); random selection of 75% of the grassland along the river Wetter and all arable land on either wet (gley soils) or dry soils (rankers)	Reduce fertilizer input; provide habitats for rich grassland vegetation and fauna
Grassland, extensive II	Land use as before, but mowing not before July; random selection of 25% of the grassland along the river Wetter	Provide nesting habitat for endangered grassland bird species; reduce fertilizer input; provide habitats for rich grassland vegetation and fauna
Apple orchards	Conversion of arable land and grassland next to relicts of formerly extensive apple orchards; directed selection of about 0.5% of the total area	Improve landscape esthethics; provide habitats for fauna
Linear landscape elements		
Extensively managed field margins	Extensive management of field margins in accordance with HIAP (but only 5 m width); all field margins along farm tracks and fields >2 ha	Provide habitats for arable vegetation, other plants, and fauna
Perennial field margins	Sowing of flowering perennial plants next to extensively managed field margins; 0.3% of the total area	Provide habitat for perennial grassland species and fauna
Hedges	Closing gaps in rudimentary hedge network	Modest improvement of the existing hedge network as habitats for plants and wildlife

[†] HIAP, Hessian Integrated Agri-environment Scheme; HMULV 2007.

ProLand:
In this analysis, ProLand calculated land rents for given exogenous spatial distributions of the various land use types in the study region. Land rent is defined as the factor income of land, i.e., for any single agricultural land use:

$$\text{Land rent} = \text{biomass yield} \times \text{product price} + \text{transfer payments} - \text{factor costs}_{\text{labor, capital}} \tag{3}$$

ProLand first estimates site-specific yields of all crops under investigation using linear-limitational yield functions. It then calculates revenues and costs for each individual field. Consequently, different input and output levels are explicitly modeled, e.g., biomass production, fertilizer input, or labor requirements. The model assumes full divisibility and unlimited supply regardless of demand at given prices of inputs and outputs. It accounts for all factor costs and thus allows comparison of agricultural land use alternatives. Land rents of crop rotations are equal to the averages of the land rents of the constituting crops weighted with their respective share in the rotation. Five conventional crop rotations with three crops each and two types of conventional grassland based on the current land use (information gained in Step 2) in the study area were defined in the BS. The changes on arable land and grassland introduced in the MS required three conventional crop rotations with four crops each, six organic rotations with five or six crops, four types of grassland, and two agri-environment schemes. Calculating land rent and transfer payment differences between the MS and BS resulted in estimates of the measures' opportunity costs. Due to the fact that N-fertilization strongly affects environmental goods, such as biodiversity or water quality, we additionally calculated the amount of N-fertilization recommended under both scenarios.

CHOICE:
The modeling and assessment framework CHOICE is based on the well-established methods of choice experiments (e.g., Hanley et al. 2001) and cost-benefit analysis (e.g., Just et al. 2004). In choice experiments, a series of alternatives for selected indicators are presented, and respondents are asked to choose their most preferred alternative. Choice experiments are particularly suited to investigate situations where changes are multidimensional and trade-offs between them are of particular interest. However, as is the case with all preference techniques, the obtained welfare estimates are sensitive to the study design, e.g., the choice of attributes, and it is important to account for cognitive difficulties associated with multiple, complex choices (Hanley et al. 2001). Therefore, the chosen indicators for this study were kept as simple as possible. We asked the local population for their willingness to pay for the following environmental goods: water quality (nitrate-N loads), plant species richness, breeding populations of birds, and landscape scenery, given five parameter values (scenarios) for each indicator. Here, we focus on the willingness to pay for alternative landscape sceneries. The five scenarios of landscape scenery (MS, BS, intensive scenario with increased field sizes, high commodity price scenario with predominance of cereals, and grassland scenario with predominance of grassland) were visualized with the help of maps and photographs. In 2007, 420 structured, personal interviews were conducted with local people between 18 and 75 years old. In the cost-benefit analysis, we calculated the consumer surplus per household resulting from a change from BS to MS and related this consumer surplus to the respective opportunity costs. Positive (Negative) results of cost-benefit analyses indicate positive (negative) impact on social welfare.

RESULTS

Step 1 resulted in a high-resolution map of today's landscape (BS, Fig. 1a, b) and related statistics (Table 3). Each arable land and grassland patch distinguished in the map was allocated to either one of the five conventional crop rotations or to one of the two types of conventional grassland management schemes to allow for site-specific modeling of the ecological and economic indicator values under the BS.

Results gained in Steps 2–4 are presented as an aggregated overview of the alternative land uses incorporated in the MS (Tables 2 and 3). In the MS, compared to the BS, the diversity of land use classes (Table 3) is considerably higher, and thus landscape structure is much more diverse (Fig. 1c). In the two scenarios, 21% of the entire acreage is in different land use, which is mainly due to the conversion of conventional arable land into alternative land uses in the MS. Here, each arable land or grassland patch

Fig. 1. Pattern of land cover/land use classes in the study area. (a) Land cover classes of the BS. (b, c) Land use classes of the BS and the MS in an exemplary subregion.

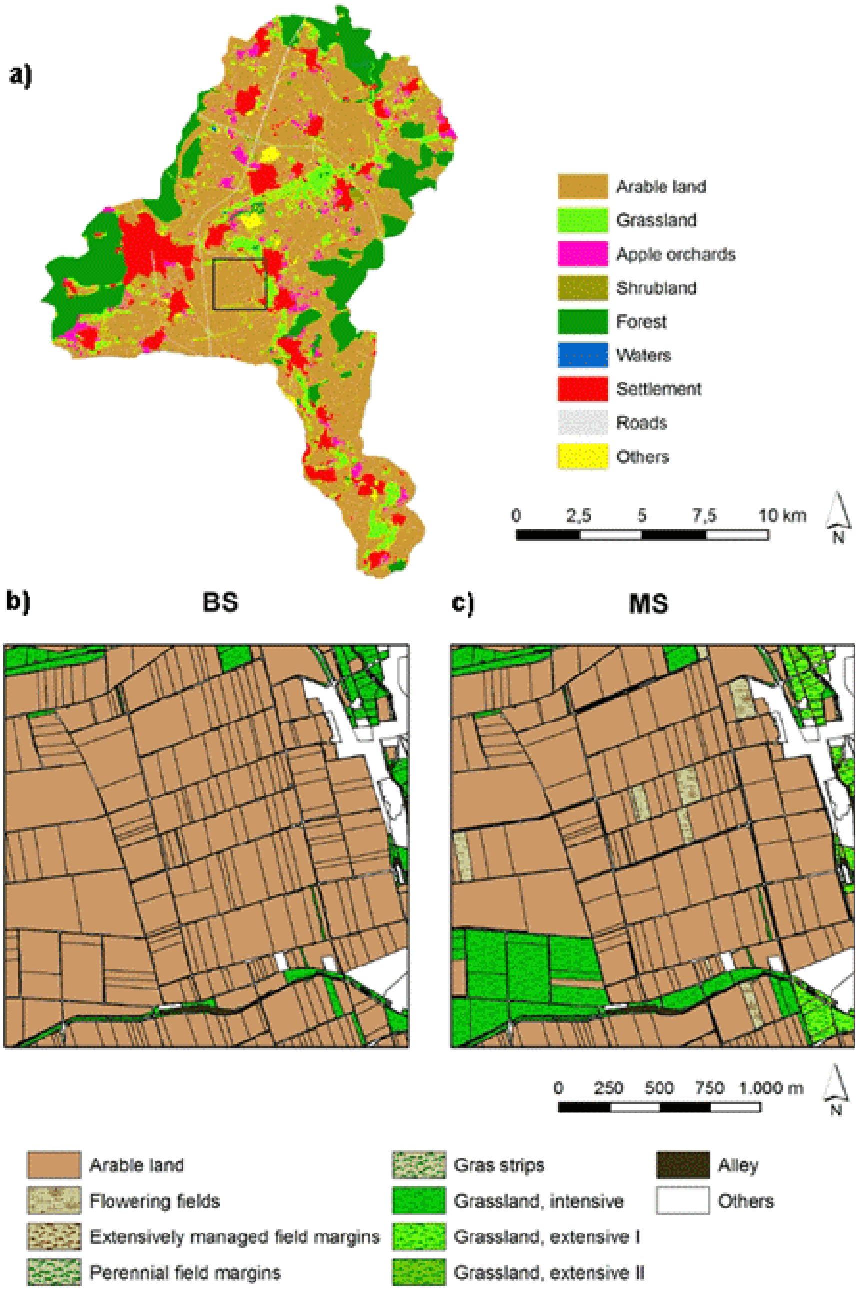


Table 3. Proportions of land uses in the BS and the MS.

	Percent (%) of Total Area	
	BS[†]	MS[‡]
Arable land, conventional	52.1	34.6
Arable land, conventional, converted to:		
Arable land, organic		8.7
Flowering fields		1.4
Extensively managed field margins		0.3
Perennial field margins		0.3
Hedges		<0.1
Grassland, intensive		3.7
Grassland, extensive I		2.0
Grassland, extensive II		0.5
Apple orchards		0.6
Grassland, intensive	8.2	3.9
Grassland, intensive, converted to:		
Grassland, extensive I		3.0
Grassland, extensive II		1.0
Hedges		<0.1
Apple orchards		0.4
Apple orchards	3.4	3.4
Grass strips	1.7	1.7
Alley	0.9	0.9
Others	33.6	33.6
Total area: 16,628 ha		

[†] BS, generalized view of today's landscape.
[‡] MS, expert-generated multifunctional landscape scenario.

was allocated to one of the conventional crop rotations, organic rotations, grassland management, or agri-environment schemes defined in ProLand modeling. These patch data and the information on linear landscape elements implemented in the MS allowed for site-specific modeling of the ecological and economic indicator values.

At the scale of the indicator-specific spatial reference units (Fig. 2, Table 4), the disciplinary evaluation of today's land use (BS) against the MS highlights functional deficits of the BS, mainly with respect to biodiversity (differences in plant species richness and Yellowhammer territories between the BS and the MS are often below zero, indicating lower biodiversity in the BS) and water quality (differences between nitrate-N loads between the BS and the MS are often above zero, indicating higher nitrate-N loads in the BS). In contrast, from the economist's view, higher land rent in the BS may result in a negative evaluation of the MS. However, in some reference units, the expected land rent is higher under the MS, indicating that today's land use is not economically optimized in all reference units. In general, the spatial pattern of areas with functional deficits in the BS differs according to the respective landscape function or service: The lower numbers of Yellowhammer territories are concentrated in the northeastern part of the study region, whereas high Cu-loads are widely spread throughout the region.

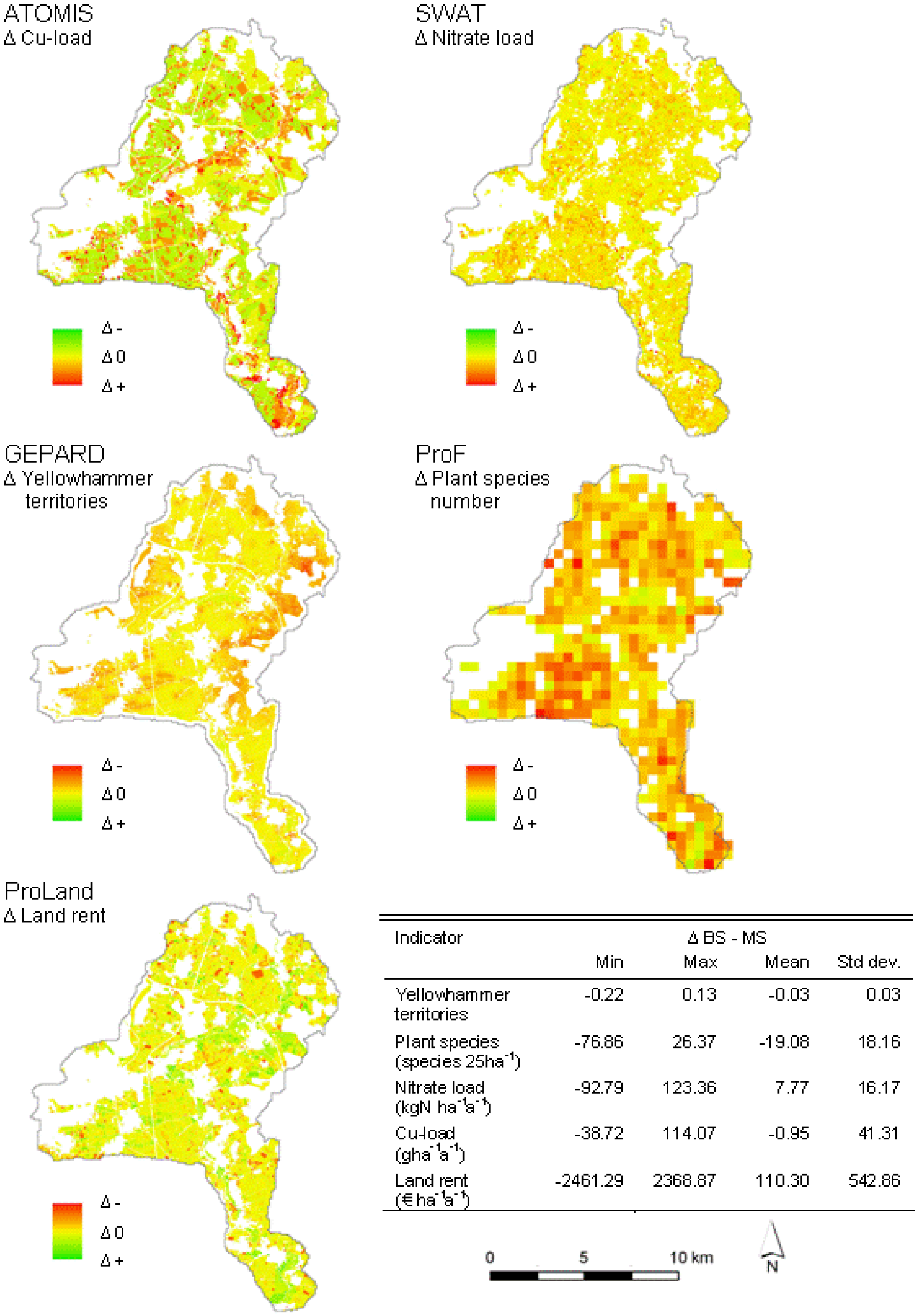
At the scale of the entire study region, Fig. 3 highlights the imbalance in the allocation of private and public goods under the BS and thus in today's landscape. On the one hand, our results clearly reveal environmental deficits under the BS for most of the indicators. For example, N- and Cd-loads are higher in the BS compared to the MS, and the numbers of Red-backed Shrike breeding populations and low-nutrient indicators in the vegetation have lower values in the BS. With respect to the indicator bird species, similar results were found for Lapwing and Little Owl. Breeding populations for the Lapwing and the Little Owl in the BS were lower than in the MS (71% and 77%, respectively). Moreover, Black-tailed Godwit and Whinchat, absent in today's landscape, are expected to occur under the MS (2 and 39 breeding populations are predicted). On the other hand, Skylark and Corn Bunting are expected to reach larger breeding populations under the BS (133% and 125%) than under the MS. The BS is therefore positively evaluated for these two bird species. This positive evaluation of the BS also holds true for the economic indicators land rent (in Fig. 3, higher indicator value in the BS) and transfer payments (lower indicator value in the BS). Average opportunity costs of the MS amount to 161 € ha^{-1} a^{-1} (decrease of land rent = 110 € ha^{-1} a^{-1}; increase of transfer payments = 51 € ha^{-1} a^{-1}). Finally, recommended N-fertilization is higher in the BS than in the MS. This result may provide the first insight into underlying ecological processes that have resulted in today's environmental deficits (higher N-loads and lower number of nutrient indicators in the BS).

Given the results at both spatial scales, the MS is evaluated as an alternative future with more desirable environmental outcomes than the current baseline. Results of the CHOICE modeling clearly show that the multifunctional scenario would also be preferred by the local population: The willingness to pay for multifunctionality (calculated implicit price = 88 €) is much higher than it is for the other scenarios of landscape scenery that were considered in the interviews (grassland scenario = 48 €; BS = 0 €; intensive scenario = –13 €; high price scenario = –16 €). Moreover, conversion of the present landscape scenery (BS) to the landscape scenery (MS) may result in a consumer surplus of 228 € per household and year. Given the number of about 40,100 households in the study region and the opportunity costs of 161 € ha^{-1} a^{-1}, the estimated net benefit of the MS amounts to 389 € ha^{-1} a^{-1}. Thus, this analysis indicates that implementation of the MS would lead to greater benefits for society.

DISCUSSION

Although the necessity of inter- and transdisciplinary studies to evaluate landscape multifunctionality has been frequently emphasized (Naveh 2001, Tress and Tress 2001, Frede et al. 2002, Helming and Wiggering 2003), integrative studies considering ecological, economic, and social landscape functions are rather scarce (but see Nassauer and Corry 2004, Santelmann et al. 2004, Wiggering et al. 2006). Fry (2001) and Tress and Tress (2001) have pointed out manifold difficulties involved in inter- and transdisciplinary landscape research, which are partly rooted in different academic traditions and languages but also in the complexity of landscape as a research object. Our approach, in which scientists generate a normative scenario by

Fig. 2. Standardized differences in indicator values as calculated for indicator-specific reference units. Standardization against min. (Δ-), mean (Δ0), and max. (Δ+) indicator values. Red color: functional deficits. Non-agricultural land (mainly forests and settlements) was excluded from data analyses.



Indicator	Δ BS - MS			
	Min	Max	Mean	Std dev.
Yellowhammer territories	-0.22	0.13	-0.03	0.03
Plant species (species $25ha^{-1}$)	-76.86	26.37	-19.08	18.16
Nitrate load (kgN $ha^{-1}a^{-1}$)	-92.79	123.36	7.77	16.17
Cu-load (g$ha^{-1}a^{-1}$)	-38.72	114.07	-0.95	41.31
Land rent (€ $ha^{-1}a^{-1}$)	-2461.29	2368.87	110.30	542.86

Table 4. Indicator values in the BS and MS at the scale of spatial reference units. (See Table 1 for spatial reference units.)

	BS				MS			
Indicator	Min.	Max.	Mean	Std. dev.	Min.	Max.	Mean	Std. dev.
Yellowhammer territories	0.00	0.33	0.05	0.06	0.00	0.34	0.07	0.07
Plant species numbers	52.54	219.39	142.17	29.93	58.68	222.50	161.25	26.23
N-load (kg N ha^{-1} a^{-1})	0.21	132.50	32.13	21.51	0.05	118.00	24.40	18.80
Cu-load (g ha^{-1} a^{-1})	38.40	146.92	122.48	28.80	32.85	183.80	123.18	53.40
Land rent (€ ha^{-1} a^{-1})	–768.79	1895.46	707.16	623.96	–986.12	2950.81	503.02	750.46

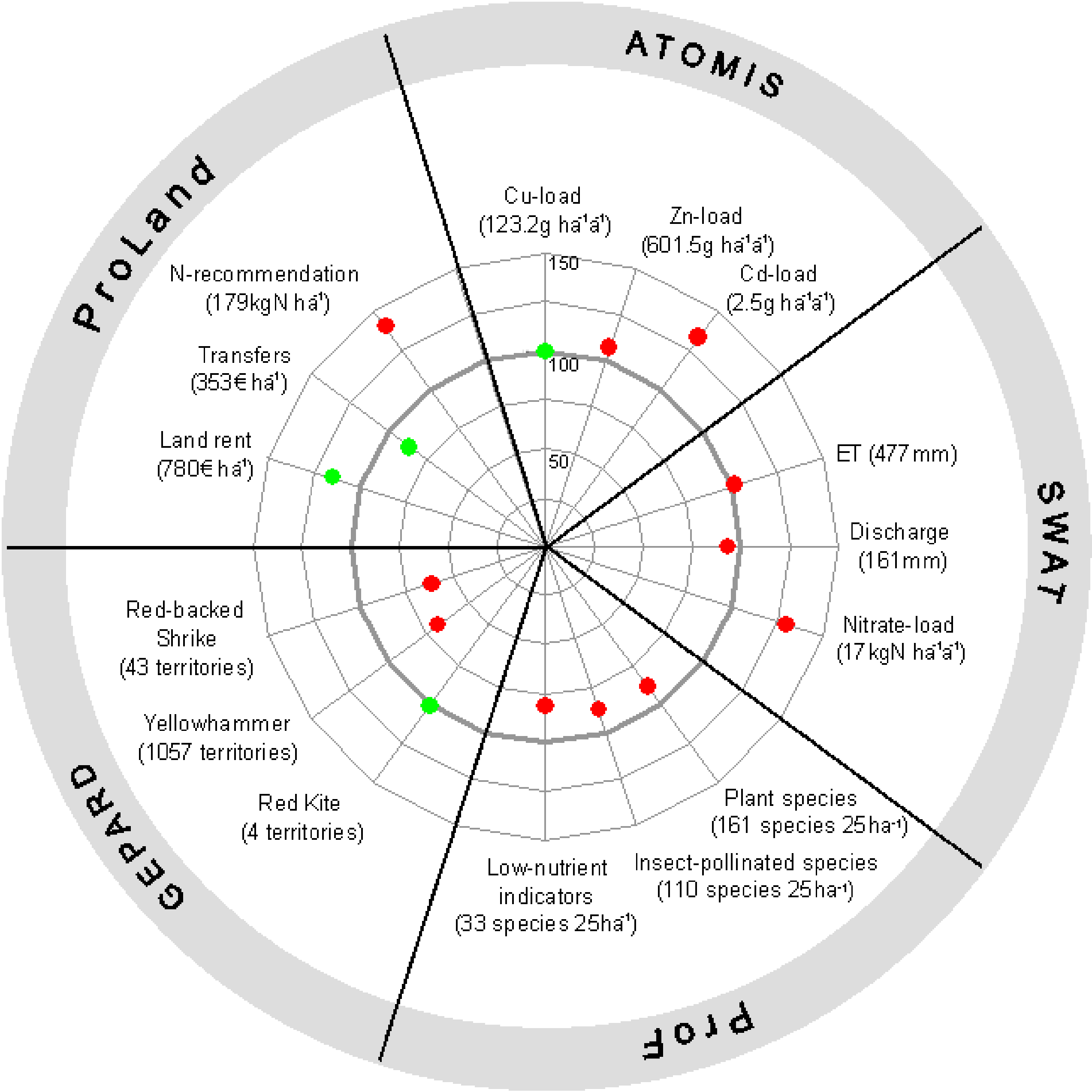
[†]BS, generalized view of today's landscape.
[‡]MS, expert-generated multifunctional landscape scenario.

drawing from regional knowledge, and subsequently, the scenario is evaluated by both scientists and lay people, may partly bridge the gap between interdisciplinary and transdisciplinary research. We did not involve nonscientists in the production but in the integrated evaluation of knowledge gained in an interdisciplinary project, and the results suggest that we produced knowledge that is not only scientifically sound but also socially acceptable. In that, the developed interdisciplinary approach possesses attributes of transdisciplinarity (cf. Gibbons and Nowotny 2001, Maasen et al. 2006).

Due to the complexity of agricultural landscapes and landscapes in general, i.e., the multitude of relationships between land use and ecological, economic, and societal landscape features, scientific research on landscape multifunctionality often concentrates on only a very limited number of landscape functions and thus evaluates only sections of the human–environment system. Moreover, future-oriented evaluation of landscape multifunctionality, similar to many other fields of landscape research, highly depends on indicator-based landscape modeling (Wiggering et al. 2006). The choice of the considered functions, indicators, and models may be scientifically justified by specific landscape settings, but also depends inevitably on pragmatic decisions reflecting regional scientific expertise or funding limitations. As a consequence, a wide range of concepts and approaches (cf. Zander et al. 2006, Renting et al. 2009) was published in previous studies related to this research field: Wiggering et al. (2006) define an indicator of social utility; Gimona and van der Horst (2007) focus on hotspots of multiple landscape functions; Groot et al. (2007) developed an "interactive multi-goal agricultural landscape generation and evaluation system"; and Parra-López et al. (2008) explicitly integrate public demands and alternatives available by the supply part of the market. Although we acknowledge that other landscapes may require different approaches, our concern here is not to identify which landscapes may require different approaches or to assess which of these concepts and approaches are most likely to result in appropriate knowledge. Rather, our purpose is to illustrate the need for and utility of spatially explicit normative landscape scenarios in the research on and evaluation of landscape multifunctionality.

Studies on landscape multifunctionality focus on either ex-post evaluation of today's landscapes or ex-ante evaluation of potential futures. Special attention has been given to political developments and decisions and their potential effects on landscape functions (e.g., Möller and Weinmann 2001, Santelmann et al. 2004, Boody et al. 2005, Sheridan and Waldhardt 2006, Gottschalk et al. 2007, Mittenzwei et al. 2007, Reger et al. 2009, cf.

Fig. 3. Integrated evaluation of today's landscape at the scale of the entire study region. Shown are indicator values of the BS in percent of the MS indicator values. Red (green) dots: Negative (Positive) evaluation of the BS in comparison to the MS. The estimated MS indicator values are given in brackets as mean/reference unit or total values. ET, evapotranspiration.



Otte et al. 2007). In these studies, potential futures were either compared among each other or related to the status quo. In an analogous way, this also holds true for studies on the sustainable development of landscapes (Rasul and Thapa 2003, Parra-López et al. 2009, cf. Büchs 2003) and on landscape services (e.g., Alcamo et al. 2005, Tscharntke et al. 2005, Müller and Burkhard 2007). In contrast to the present paper, these studies did not use a normative reference landscape to evaluate the degree of multifunctionality, sustainability, or services that could be achieved in a given landscape. In general, only few spatially explicit research efforts (e.g., Meyer and Grabaum 2008) have been undertaken to develop multifunctional futures at the landscape scale. Our normative scenario approach may encourage other research teams to explore the potential landscape multifunctionality and sustainability using normative future scenarios rather than current baseline landscapes as the benchmark for evaluation of multifunctionality and sustainability.

Our approach to design one multifunctional reference landscape, albeit founded on interdisciplinary scientific knowledge, will likely generate different results depending on the participating disciplines, researchers, and also on the information gained in the first three steps of the process. Although our alternative future was expected to positively affect landscape multifunctionality from our scientific perspective, the rules we determined and the landscape we designed should not be seen as the only solution for landscape multifunctionality. Considering the multiplicity of landscapes and landscape functions, any given landscape should be viewed as being positioned in a broader multidimensional space of landscape functions. Within this multidimensional space, multifunctional landscapes are located within the domains limited by the lower threshold values of (indicators of) landscape functions. Hence, there are potentially a large number of possible solutions to landscape multifunctionality. In that, the results of the fourth and fifth steps of our approach presented here may be considered as a first pass of an iterative procedure to develop and evaluate additional alternative futures within the domain of landscape multifunctionality.

Further, a designed multifunctional future represents only a snapshot in time due to changing input and output prices and changing societal demands (Alcamo et al. 2005, Huber et al. 2007, Jongeneel et al. 2008). Recent developments of rising input costs and declining output prices may result in lower overall estimates of the land rent. Moreover, politically induced market distortions, such as bioenergy support, may introduce new biomass crops, which are economically more profitable than current cropping systems. Such interventions will possibly lead to an increase of opportunity costs.

Our results at the scale of indicator-specific spatial reference units show that the designed alternative future cannot simultaneously decrease environmental deficits in all spatial reference units. In some parts of the landscape under study, environmental deficits are even expected to increase, if today's landscape is altered according to the normative scenario. Moreover, biotic indicators, even if they belong to the same indicator species group (e.g., bird species considered in this study; cf. also Gottschalk et al. 2010), may be affected in opposite directions. In general, these effects reflect both specific landscape settings and modeling rules (e.g., species' habitat preferences) applied in the ITE²M models. Consequently, disciplinary cause–effect analyses within the ITE²M model network could improve the understanding of the relationships between land use and the degree of landscape functionality and should allow for an iterative development of additional alternative futures. In such an extended approach, many more indicators (e.g., different species groups) and additional landscape functions (cf. De Groot 2006) than presented in this study may also be integrated. As part of an ongoing research project at Giessen University, a landscape model on land use-dependent CO_2 emission has been developed and integrated within the ITE²M network.

Despite the limitations discussed above, our evaluation of landscape multifunctionality in the Wetterau region highlights a strongly unbalanced allocation of private and public goods in today's landscape: Severe deficits in environmental and societal landscape features go hand in hand with high land rent. Thus, a modification of today's landscape is imperative to meet the requirements of landscape multifunctionality in the study region. In this context, the normative scenario designed to increase landscape multifunctionality may be viewed as one alternative future toward a balance of productive and nonproductive functions in the study region. We are aware of the limited potential of landscape modeling approaches to contribute to multifunctional agriculture (cf. Groot et al. 2009). As outlined in *Methodology*, we also acknowledge potential limitations in using willingness to pay data in the economic evaluation of our scenarios.

Nevertheless, we hope that our results may stimulate decision makers and farmers to adapt and expand the implementation of agri-environment schemes, which will eventually lead to more multifunctional landscapes. According to our results, today's land use is not economically optimized in all reference units. Our results should encourage farmers to consider conversion to alternative production systems used in our scenario, such as organic farming.

Our results suggest that spatially explicit, informed decision making will be required to achieve agricultural landscapes in which land use meets the needs of the ecosystem and society at the patch as well as the landscape scale. But even if this challenge is met, the alleged dilemma of trade-offs among landscape functions remains unsolved. Conflicting and contradicting states of landscape functions are inherent characteristics of the ecosystem "landscape" and are of fundamental importance for self-organization and positive feedbacks in disturbed landscapes (cf. Perry 2002). However, the ultimate goal of sustainable land use management is to find balanced compromises between environmental, societal, and economic landscape functions. The approach presented here may be of use in finding these compromises.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss3/art30/responses/

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