Environmental and Economic Impact of Agricultural Land Use

- a Spatially Explicit DEA Approach -

Kapfer M.[1], Kantelhardt J.[1], Eckstein K.[2] and Hübner R.[2]

[1] University of Natural Resources and Life Sciences/Agricultural and Forestry Economics, Vienna, Austria
[2] Technische Universität München/Farm Economics and Management, Munich, Germany

martin.kapfer@boku.ac.at

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Summary

Agriculture produce commodities and but also influence the environment. However, even if the value of commodities is easy to determine, it is difficult to assess the efficiency of agricultural production at site level. Furthermore, the valuation of environmental impact is complex. Non-parametric approaches such as DEA allow for an assessment of environment and economic performance. We implement a plot-specific approach combining GIS and DEA models. This allows a spatially explicit assessment of agricultural land use for different subjects such as ecology and economy. In a second stage DEA-model, the impact of farm- and site-specific characteristics on efficiency is analysed.

Keywords: agricultural land use, data envelopment, environment-oriented technical efficiency, economy-oriented technical efficiency

JEL Classification codes: Q12, Q26,Q57

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1 INTRODUCTION

The major aim of agricultural enterprises is to generate income from commodity production in order to guarantee a certain standard of living for farmers and their families. But agriculture also has significant effects on the environment and landscape aesthetics – so-called external effects. For example, the application of mineral fertilizers can cause environmental damage to biodiversity or water quality – one example of a typical negative external effect. With respect to landscape appearance, agriculture forms the cultural landscape which is socially desirable, thus creating positive external effects.

Since agricultural land use is strongly linked to the single plot as the location of production, a site-specific view of external effects is sought after but has not until now been a common feature in the evaluation of externalities. For this study, a number of significant variables are selected which cover a specific indicator function. The second major challenge in this context is the combination of data within geographic information systems (GIS) with non-parametric methods such as the Data Envelopment Analysis (DEA). This approach seems to be a way of measuring the performance of agricultural land use in terms of economy as well as in terms of producing (positive and negative) externalities.

This paper presents such an approach in the study region “Rhön” in northern Bavaria.

2 MATERIAL AND METHODS

2.1 Study region

The study area “Rhön”, located in the low-mountain range, is typical for low-yield marginal sites and thus for regions which are threatened by the withdrawal of agriculture. It is important to safeguard the farms in this region in order to continue the long-term preservation of a highly structured and – from a conservation perspective – valuable cultural landscape (LFU, 2010). Geographically the study area is the northern section of the “Hohe Rhön”, a tertiary basalt plateau with peaks in the range of 800 m a.s.l. The open areas of the hilltops are very low-yield sites. Agricultural use is restricted to pastures for sheep and cattle as well as extensive meadows, cut twice (Figure 1). Typical features are spacious, mosaic-like diverse meadow communities, large perennial matgrass meadows (Nardus stricta), mountain hay meadows, valuable marsh meadows and several moor areas.

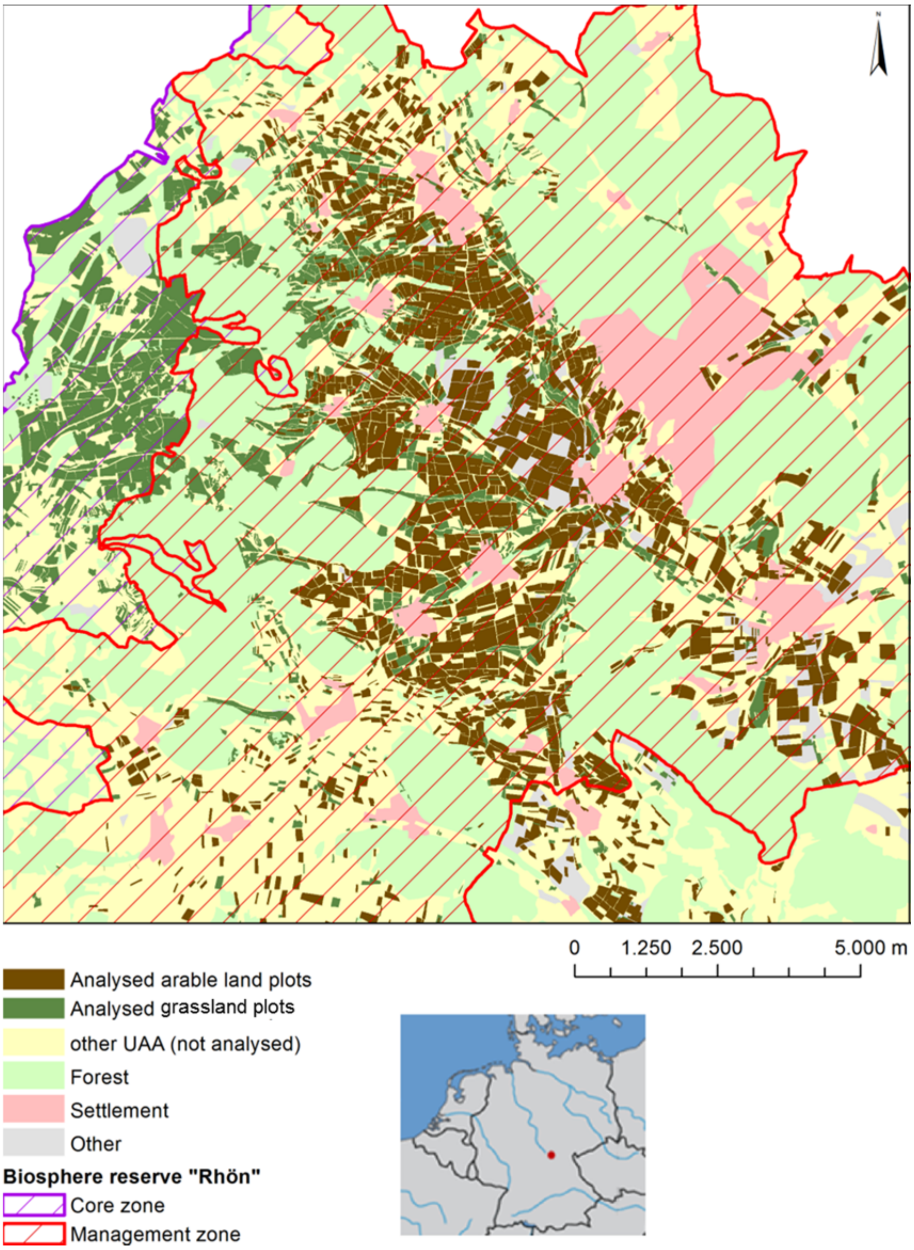
Figure 1: The open areas of the hilltops are being used as pastures and extensive meadows.

Figure 2: A mixture of forest and grassland areas is characteristic for the slopes.

The eastern slope falls steeply, approximately 300 m, to the valley bottom known as “Fladunger Mulde”. These slopes are dominated by forest (Figure 2). Here the waters have cut deep, so that a series of wooded ridges and grassland valleys has developed. The forest-free areas in-between are used exclusively as a two- or threefold cutting meadow. The land-use pattern in the map in Figure 3 shows that the valley plains of the “Fladunger Mulde” are used almost entirely for arable farming. The sites can still be described as marginal. Shrubs along water bodies, hedges and orchards are the typical landscape structures.

The farms in the study area are generally small in size and form, with some exemptions, primarily a side-line income. The average livestock density is comparatively low at 0.5 livestock units (LUs) per hectare. Due to the occurrence of extremely rare species the area is a Fauna-Flora-Habitat-area (FFH) “Hohe Rhön”, part of the European network Natura 2000. Furthermore, the region is also protected as biosphere reserve “Rhön”, from which the “core zone” and the “management zone” are depicted in figure 3.

Figure 3: Overview on plot structure and land-use type of the study area "Rhön".



2.2 *Methodical approach of a spatially explicit DEA*

For calculating the agricultural contribution to environmental services and to the benefits for landscape, the Data Envelopment Analysis (DEA) is used. DEA is a non-parametric mathematical programming approach enabling the comparison of the efficiency of production performances.

2.2.1 *Suitability of the DEA approach*

By using the DEA approach, it is possible to consider multiple inputs and outputs which can have different units. Consequently, even factors which cannot (or only at great expense) be expressed in monetary units can be included in the assessment. This technique thus allows the integration of multiple economic and environmental aspects such as the prevention of nitrate leakage, the amount of pesticide application and the workload.

The production performance is rated by calculating the output-to-input ratio of the respective production processes; the less input required for producing a given output or the more output produced with a given input, the higher the efficiency score. Our study is based on analysing single plots. The final efficiency score is derived within a DEA by benchmarking the output-to-input ratio of an individual plot against the output-to-input ratio of those plots with the best performance (Cooper et al., 2006). Thus, DEA compares single plots not to the average of the sample, but to the best ones.

At farm level, DEA has been already conducted in several studies to measure environmental efficiency. For instance, Reinhard et al. (2000) calculated the environmental efficiency of Dutch dairy farms and De Koeijer et al. (2002) measured the sustainability effects of Dutch sugar beet growers by taking into account the ecological efficiency. Dreesman (2006) analysed the productivity and the efficiency of agricultural farms, taking into account not only production inputs and outputs but also environmental effects.

Certainly the quality of environmental services is often plot specific, depending on the single plot management, the specific site conditions or the adjacent area. In our study, we conduct a DEA-efficiency analysis at plot level to investigate the spatial difference of e services or the contribution to landscape benefits. Thus, the decision is made as to what types and quantities of input (e.g. fertilizers, pesticides) are used and what types and quantities of output are produced at plot level.

To calculate plot efficiencies, the ordinary Charnes-Cooper-Rhodes (CCR) model is used (Cooper et al., 2006). DEA offers the choice between input- or output-oriented value calculations. For our analysis, the output-oriented model was used, which means that the input variables are held constant while DEA tries to maximise the output (Coelli and Rao, 2003). The rationale for doing so is that agricultural production (e.g. yield) should be optimized simultaneously with the provision of environmental goods in our 1st DEA-analysis and the contribution to landscape appearance in our 2nd analysis. For the provision of agri-environmental services, no economies of scale are assumed. The linear programming (LP) problem to be solved for each plot is as follows:

$$\begin{aligned} &\max_{\phi,\lambda} \phi \\ \text{s.t. } &-\phi y_i + Y\lambda \geq 0 \\ &x_i - X\lambda \geq 0 \\ &\lambda \in R_+ \end{aligned} \tag{1}$$

where ϕ is a scalar, λ is a (N x 1) vector of weights, X is a (N x K) matrix of input quantities for all N plots, Y is a (N x M) matrix of output quantities for all N plots, x_i is a (K x 1) vector of input quantities for the ith plot and y_i is a (M x 1) vector of output quantities for the ith plot. Note that the technical efficiency, abbreviated as θ, in this paper is defined as $1/\phi$.

DEA makes assumptions that all objects of investigation are comparable in the case of available means of production and available resources (inputs) and the potential output of products and services (Dyson et al., 2001). As at plot level, the management of arable land and grassland is totally different; we separate the sample of plots into these two main types of cultivation. This means that we calculated two different types of efficiency for grassland plots and two different types of efficiency for arable plots respectively: the economic-oriented technical efficiency, θ_{econ} and the environment-oriented technical efficiency θ_{env} (Table 1). While the production factors of land, capital and workload serve as input for the economic- oriented analysis, land is the only input variable for the environment-oriented data envelopment analysis. Regarding output, side profit is considered as the only output variable of the economic-oriented efficiency estimation. This applies for calculations on grassland as well as on arable land plots. Regarding environment-oriented output variables, one has to differentiate between arable and grassland plots: on arable land the use of plant-protection products, the total nitrogen application, and the nitrogen surplus are considered. On grassland indicators which stand for the intensity of agricultural land use are the total nitrogen application and the nitrogen surplus. Additionally the yield level was incorporated as an additional output variable, in the sense that a high-yield potential stands for a high intensity of use.

Table 1. List of considered variables:

		Economy-oriented technical efficiency θ_{econ}		Environment-oriented technical efficiency θ_{env}	
		grassland	arable land	grassland	arable land
input	Land	x	x	x	x
	Capital	x	x		
	Workload	x	x		
ouput	Profit	x	x		
	PPP			x	
	Total nitrogen application			x	x
	Nitrogen surplus			x	x
	Grassland yield				x

A shortcoming of DEA is that outputs are interpreted as something clearly desirable; con-sequently, higher output levels result in higher efficiency values. In fact, regarding the output variables of the environment oriented DEA, chosen outputs which affect the environment resources performance represent typical negative external effects. For instance, excess nitrogen application and the application of pesticides are such undesirable outputs considered in our study. Therefore, undesirable and thus negative outputs had to be reversed, in order to be correctly interpreted by DEA (c.f. Scheel, 2000).

2.2.2 Assignment of input and output variables

Our study is conducted by analysing data of the integrated administration and control sys-tem (IACS-data) and digital field maps of about 5,800 plots with a unique field identifier (FID) belonging to 95 farms. As object of investigation (decision making unit, DMU), the single plot is chosen. Area-specific information sources such as the biotope mapping of the state of Bavaria, the register of protected areas and the land-cover map complete the GIS-Data system. In addition to the IACS-Data, economic, socioeconomic and environmental indicators at plot level such as capital, workforce, profit, yields and N-surplus are calculated from standard data, taking into account the land use and production scheme of the farms, as well as regional statistics and site-specific attributes. In the following, the utilized variables are described in detail.

Profit was calculated as the difference between operating income and expenses at single- plot level (in detail, see Annexe I)

Capital includes fixed and current assets in order to maintain production. This farm-level-derived key figure has to be assigned to each plot of a farm. It is assumed that the share of "whole-farm" capital which is assigned to a single plot is equal to the ratio of single-plot gross margin to total gross margin of the considered farm.

Workload: The workload was calculated according to Handler et al. (2006) for different areas of production levels (cash cropping, feed-crop production, grassland cultivation, other forms of land use, husbandry separated into granivores and grazing stock), management etc. The plot-individual workload was calculated according to crop rotation. Workload from grazing stock husbandry was integrated according to the fodder energy provision of grassland and feed-crop production at single-plot level. The workload in granivore production at single-plot level was estimated according to fodder grain need in husbandry and grain production at single-plot level.

Plant-protection products: The use of PPP is taken from the recommendations by the Bavarian State Institute for Agriculture (LfL/ILB, 2010). For the calculations of the PPP-needs, the appropriate average crop rotation on arable land of the farm is assumed out of the IACS-Data; thus the yield level was taken into account. The amount of PPP is presented in € per hectare, so relative differences between crops are represented.

Nitrogen surplus: The N-surplus refers to the potential nitrogen surplus on agricultural land and provides an indication of potential water pollution due to nitrogen leakage. Water pollution by nitrates is one of the main problems from agricultural activities, because nitrate is well soluble and can easily pass through the soil or via surface runoff into water bodies. For the study, the nitrogen surplus is determined in form of a simplified farm-gate balance by calculating the difference between the total need of nitrogen, depending on the cultivated crops and the yield level and the total amount of applied nitrogen (Formula 1)[1] .

$$Nbal_{FID} = (Nsup_{FID} - Ndem_{FID}) \quad (2)$$

Nitrogen supply: The nitrogen supply is calculated as the total amount of organic (N_{org}) and mineral nitrogen (N_{min}) applied (Formula 2).

$$Nsup_{FID} = N_{org} + N_{min} \quad (3)$$

The amount of N_{org} applied results from the animal husbandry of the farms (see Formula 5 in the Annexe), assuming that during application an estimated 60 % is utilized only. The amount of applied N_{min} results from the crop-specific needs in addition to the amount of N_{org}, while leakages, as well as the cultivation of legumes, are taken into account (Formula 6 in the Annexe II)[2].

Grassland yield: The input factor yield at harvest constitutes a natural disadvantage of the productivity of the soil and is therefore an expression of the agricultural usability of a parcel. The value is obtained from the Land Registry for each single plot. The calculation basis is the outcome of the soil evaluation mapping of the respective area.

2.2.3 Second stage DEA calculations

DEA efficiency scores might be influenced by external environmental factors, which cannot be controlled by farmers. In order to estimate the influence of such factors on our results, we employ a two-stage DEA model. This means that we treat DEA efficiency scores (derived at the first stage of our analysis) at a second stage as a dependent variable and regress it on external environmental factors. Since DEA efficiency scores are censored between 0 and 1, we apply a Tobit-regression using the Tobit function of the R-package AER. In order to get an idea of which external factors are the most relevant ones, we distinguish two types of factors, namely “site-conditions related factors” and “farm-organisational factors”.

[1] For detailed calculation steps see Formulas (4) to (9) in Annexe II.
[2] Excess quantities of N_{org} are assumed to be distributed pro rata to the farm areas. Where there is a difference between organic fertilizers, accrue and demand is balanced with mineral nitrogen, of course, with the exception of organic-producing areas.

3. RESULTS

3.1 Statistical analysis of data

Table 2 summarises the results of the statistical analysis of the chosen input and output variables. One can see that in general the plot size is very small in the study region. This is due to the mountainous topography and the unfavourable land tenure. With an average plot size of 1.3 ha on arable land and only 0.9 ha on grassland, the fragmented characteristic of the landscape becomes imaginable. On average, the profit is negative, with a wide range. This is due to the fact that the study region is very marginal and that very small part-time farms, often not initially looking for economic success, cultivate a high share of the study region. Regarding the economic variables, it is obvious that, in general, profit – as well as capital and workload on grassland plots – is higher than on arable land plots. This is due to the fact that almost every grassland plot belongs to a husbandry farm, while the numerous arable land plots are managed by cash-crop farms.

Generally, due to the bad growing conditions, the use of PPP and nitrogen is at a low level. Remarkably, although the total application of nitrogen is higher on arable land, on grassland there is a larger surplus. This indicates even worse growing conditions on grassland, which can be confirmed by an average yield of only 45 dt/ha grassland. The remuneration for participation in AEP is considerably higher on grassland than on arable land. This is because the requirements for the grassland measures are comparatively higher, as the use of mineral fertilizer is totally prohibited and a limit of livestock units must be complied with.

Table 2. Statistical description of input and output variables.

variable		grassland	arable land
number of plots		2,889	2,843
plot size (ha)	mean	0.9	1.3
	SD	1.53	1,42
profit (EUR/ha)	mean	-137	-217
	SD	631	378
capital (EUR/ha)	mean	6,990	4,976
	SD	3,556	1,919
workload (AWU/ha)	mean	78	37
	SD	51	20
plant-protection products (PPP) (EUR/ha)	mean		62
	SD		33
nitrogen use (kg/ha)	mean	48	123
	SD	88	59
nitrogen surplus (kg/ha)	mean	53	26
	SD	263	100
grassland yield (dt/ha)	mean	45	
	SD	16	

3.2 Economy-oriented efficiency results

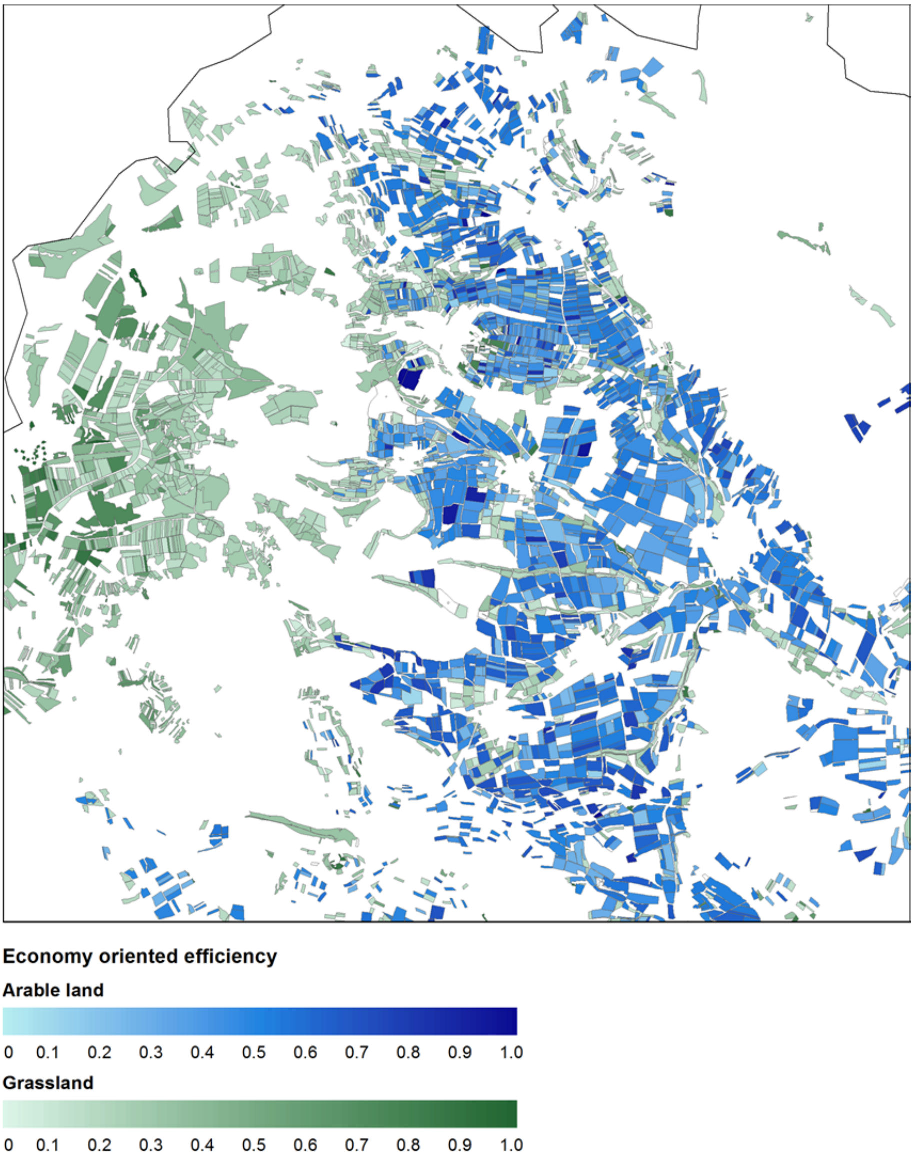
The mean economy oriented efficiency values θ_{econ} are shown in Table 3. Here the mean efficiency of the two land-use types is quite different. While the mean efficiency on arable land is about 0.48, on grassland only a mean score of 0.29 is reached. This is due to the fact that only a few plots reach high economy-oriented efficiency scores. The lower mean efficiency scores on grassland may be an indicator of the low economic potential of extensive grassland use in this marginal study region. The few plots reaching high efficiency scores are managed by a reasonably large and, in comparison to the others, intensive dairy farm. On arable land, one can observe a more homogeneous situation. This might be because of the lack resp. minor importance of husbandry in arable land production.

Table 3. Economy-oriented technical efficiency θ_{econ} of land-use type.

	grassland	arable land
mean	0.29	0.48
min/max	0.008/1.0	0.011/1.0
SD	0.19	0.16

Figure 4 shows the spatial distribution of the economy-oriented efficiency scores.

Figure 4: Economy-oriented technical efficiency in the study region “Rhön”.



3.3 Environment oriented efficiency results

The mean environment efficiency θ_{env} for grassland and arable land are quite similar, reaching 0.87 and 0.76 respectively. However, it is remarkable that the spread of efficiency scores seems to be wider on arable land than on grassland. In particular the probability for the occurrence of very low efficiency values is higher on arable land. Possibly, the wide range of intensive farm management on the one hand, and the participation in AEP on the other, becomes visible in the standard deviation of efficiency scores on arable land. In contrast, the standard deviation of efficiency scores on grassland is narrower because the possible grassland management regimes are, due to their low site-quality conditions, similar in their intensity.

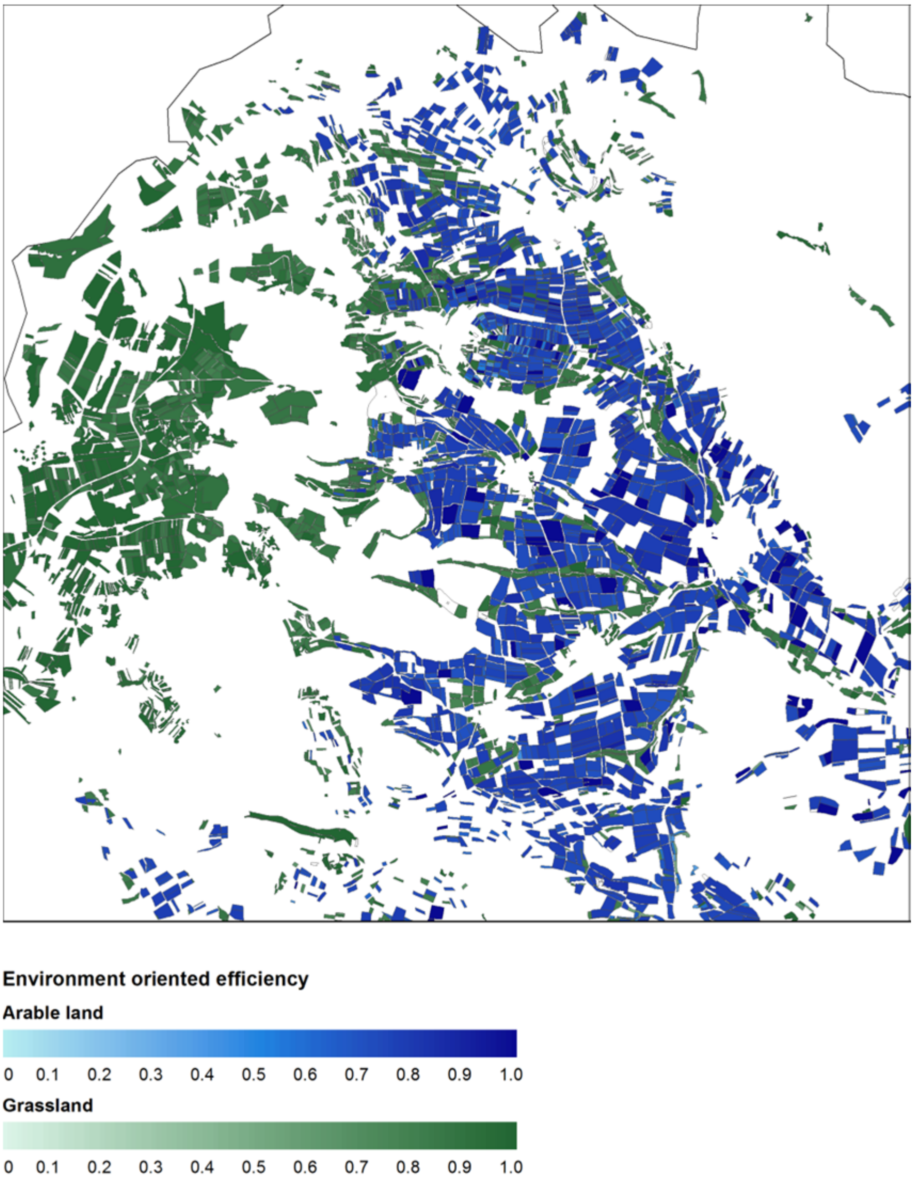
Table 4. Environment-oriented technical efficiency θ_{env} of land-use type.

	grassland	arable land
mean	0.87	0.76
min/max	0.09/1.0	0.16/1.0
SD	0.10	0.12

The spatial distribution of the environmental efficiency values is presented in figure 5. Regarding the grassland plots, which are mainly located in the western part of the study region, the minor heterogeneity of θ_{env} is typical. This indicates that the site conditions, as well as the management of the grassland plots, are of lower diversity. Only a few plots are noticeable in the sample for very low environmental services.

In figure 5 one can see a bigger heterogeneity in environmental efficiency scores θ_{env} on arable land, in the form of a patchwork of different scores side by side. This indicates that on arable land a wider range of production intensities – depending, for example, on crop rotation – have external effects.

Figure 5: Environment-oriented technical efficiency values in the study region "Rhön".



3.4 Influence of site conditions on efficiency scores

The results of the Tobit regressions show that on both land-use types, arable land and grassland, site quality has a remarkable influence on efficiency scores in the economic as well as in the environmental consideration (Table 5 to Table 8).

From a closer analysis of the results, one can see that factors such as slope and the area of a plot covered with mapped biotopes have a significant influence on the economy-oriented efficiency score on grassland (Table 5). Even if the regression coefficient R^2 in Tobit models cannot be interpreted as a measure of how well the regression line approximates the real data points, it hints at the influence of the model quality. Being sure of this fact, one can estimate that on grassland plots the chosen coefficients together determine about 0.11 of economic (Table 5) and 0.14 environmental (Table 7) efficiency scores. The location of the plot, outside or inside the biosphere reserve (differentiated in core and management zones), has a higher influence on economic than on ecological efficiency. In addition to this, it is surprising that the coefficient for "plot located in the core zone of the biosphere reserve" for the economic efficiency score is positive, so that plots inside the core zone perform better according to the model. Furthermore, one can say that the slope has a significant influence on environmental but not on economic performance.

Table 5. Results of regression analysis for economic-oriented efficiency scores on grassland concerning plot specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.	
Constant	9.538e-01	1.312e-02	72.673	< 2e-16	***
Plot size	8.788e-03	1.818e-03	4.834	1.34e-06	***
slope	-6.052e-02	4.996e-02	-1.212	0.2257	
yield index units	-1.735e-05	2.235e-06	-7.761	8.44e-15	***
biosphere reserve (core zone)	2.653e-02	1.282e-02	2.070	0.0384	*
biosphere reserve (management zone)	-3.086e-02	7.181e-03	-4.298	1.73e-05	***
area covered with mapped biotops	2.561e-03	2.592e-03	0.988	0.3230	

*** significant on 0.001 level
* significant on 0,05 level

Log-likelihood: 750.7
Wald-statistic: 439.7
p-value: < 2.22e-16
Pseudo-R^2 = 0.1176875

The results concerning arable land plots differ from the ones concerning grassland. In arable land use, the R^2 in the economy case is slightly higher than on grassland plots (appr. 0.16); for the environment, the situation is the opposite ($R^2 \approx 0.09$). This might be a consequence of the less narrow relationship between land use and husbandry in arable land use. As on grassland plots in the arable land case the area of mapped biotopes has no significant influence on efficiency scores.

Table 6. Results of regression analysis for economic-oriented efficiency scores on arable land concerning plot specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.	
Constant	6.95e-01	1.32e-02	52.605	< 2e-16	***
Plot size	-2.32e-03	2.10e-03	-1.105	0.269	
slope	-2.26e-01	4.95e-02	-4.571	4.85e-06	***
yield index units	-3.33e-03	2.71e-04	-12.258	< 2e-16	***
biosphere reserve (management zone)	-6.73e-02	6.63e-03	-10.143	< 2e-16	***
area covered with mapped biotopes	-3.08e-02	1.97e-02	-1.565	0.118	

*** significant on 0.001 level

Log-likelihood: 1,396
Wald-statistic: 292.4
p-value: < 2.22e-16
Pseudo-R^2 = 0.1551

Table 7. Results of regression analysis for environmental-oriented efficiency scores on grassland concerning plot specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.
Constant	6.165e-01	1.855e-02	33.232	< 2e-16***
Plot size	-1.755e-03	2.386e-03	-0.736	0.462
slope	-4.771e-01	7.295e-02	-6.540	6.14e-11***
yield index units	-4.799e-05	3.188e-06	-15.053	< 2e-16***
biosphere reserve (core zone)	-1.803e-01	1.805e-02	-9.990	< 2e-16***
biosphere reserve (management zone)	-1.506e-01	1.043e-02	-14.446	< 2e-16***
area covered with mapped biotopes	-2.376e-03	3.611e-03	-0.658	0.511

*** significant on 0.001 level

Log-likelihood: 679.5
Wald-statistic: 429
p-value: < 2.22e-16
Pseudo-R^2 = 0.135735

Table 8. Results of regression analysis for environmental-oriented efficiency scores on arable land concerning plot specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.	
Constant	7.88e-01	1.43e-02	55.102	< 2e-16	***
Plot size	2.71e-02	2.41e-03	11.237	< 2e-16	***
slope	2.08e-01	5.34e-02	3.891	9.96e-05	***
yield index units	9.64e-04	2.94e-04	3.284	0.00102	**
biosphere reserve (management zone)	-8.94e-02	7.32e-03	-12.224	< 2e-16	***
area covered with mapped biotopes	-3.48e-02	2.08e-02	-1.674	0.09419	.

*** significant on 0.001 level
** significant on 0.01 level
. significant on 0,1 level

Log-likelihood: 259.6
Wald-statistic: 320.6
p-value: < 2.22e-16
Pseudo-R^2 = 0.08571998

3.5 *Influence of farm organisation on efficiency scores*

To determine the influence of farm specific attributes, such as farm size or farm type on plot-specific economic and environmental performance, a second Tobit model was generated. The results of these regressions are depicted in Table 9 to Table 12. In general, these regressions show that farm size, farm type and farm organisation have a higher impact on economic and environmental efficiency scores, whether one looks at grassland or arable land plots. The regression coefficients reach a rough range from about 0.39, which means that over one-third of the variation of the efficiency scores at single-plot level can be traced on (whole) farm management. The result show that the farm type (dairy, other grazing livestock, cash cropping and mixed farms) in particular has a significant impact on economic and environmental performance. In addition to that, one can say that the higher the number of livestock, the lower economic and environmental performance on grassland, while on arable land a higher number of livestock induces lower economic but higher environmental efficiency scores. Furthermore one should mention that farm size has a significant positive effect on economic and environmental efficiency scores on grassland and arable land plots. While it seems quite clear that this applies to economic performance, this result might be surprising for environmental aspects. Perhaps smaller farms operate more intensively due to the scarcity of the production factor “agricultural land”. The marginality of the study region might be one reason why on average organic farms perform better in the field of economy. Higher prices and AEM-payments overcompensate the yield reduction.

Table 9. Results of regression analysis for economic-oriented efficiency scores on grassland concerning farm-specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.
Constant	9.115e-01	6.026e-03	151.251	< 2e-16 ***
UAA (farm)	8.049e-04	4.374e-05	18.403	< 2e-16 ***
LU (farm)	-7.241e-04	3.537e-05	-20.474	< 2e-16 ***
Farm type:dairy farm	-7.081e-02	7.057e-03	-10.034	< 2e-16 ***
Farm type: other grazing livestock	2.585e-02	7.542e-03	3.428	0.000608 ***
Farm type: cash crops	-1.771e-02	7.830e-03	-2.262	0.023690 *
Organic farming	5.852e-02	9.617e-03	6.086	1.16e-09 ***

*** significant on 0.001 level
* significant on 0,05 level

Log-likelihood: 1,118
Wald-statistic: 1,427
p-value: < 2.22e-16
pseudo-R^2 = 0.3944852

Table 10. Results of regression analysis for economic-oriented efficiency scores on arable land concerning farm-specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.
Constant	2.685e-01	1.135e-02	23.658	< 2e-16***
UAA (farm)	8.684e-04	4.774e-05	18.189	< 2e-16***
LU (farm)	-4.145e-05	4.013e-05	-1.033	0.30166
Farm type:dairy farm	1.469e-01	8.634e-03	17.014	< 2e-16***
Farm type: other grazing livestock	1.402e-01	1.371e-02	10.228	< 2e-16***
Farm type: cash crops	1.070e-01	7.428e-03	14.407	< 2e-16***
Organic farming	6.165e-03	8.141e-03	0.757	0.44891
share of area covered with erosion-prone crops (farm)	-3.590e-01	2.652e-02	-13.539	< 2e-16***
number of crop rotation elements	4.504e-03	1.388e-03	3.245	0.00117 **

*** significant on 0.001 level
** significant on 0.01 level

Log-likelihood: 2,023
Wald-statistic: 1,974
p-value: < 2.22e-16
Pseudo-R^2 = 0.3845748

Table 11. Results of regression analysis for environmental-oriented efficiency scores on grassland concerning farm specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value.	prob
Constant	2.245e-01	1.003e-02	22.373	< 2e-16 ***
UAA (farm)	1.615e-03	7.280e-05	22.186	< 2e-16 ***
LU (farm)	-7.430e-04	5.896e-05	-12.601	< 2e-16 ***
Farm type:dairy farm	-5.800e-02	1.188e-02	-4.881	1.05e-06 ***
Farm type: other grazing livestock	4.700e-02	1.240e-02	3.789	0.000151 ***
Farm type: cash crops	-4.820e-02	1.292e-02	-3.731	0.000191 ***
Organic farming	-6.423e-02	1.575e-02	-4.078	4.55e-05 ***

*** significant on 0.001 level

Log-likelihood: 812
Wald-statistic: 752.2
p-value: < 2.22e-16
R^2 = 0.2177623

Table 12. Results of regression analysis for environmental-oriented efficiency scores on arable land concerning farm specific attributes (Tobit Model).

Variable	Coefficient	Std. Error	z-value	prob.
Constant	8.34e-01	1.07e-02	77.954	<2e-16***
UAA (farm)	9.79e-02	4.60e-03	21.277	<2e-16***
LU (farm)	1.18e-02	3.82e-03	3.076	0.0021**
Farm type:dairy farm	-1.02e-01	8.22e-03	-12.441	<2e-16***
Farm type: other grazing livestock	-3.01e-02	1.29e-02	-2.332	0.0197*
Farm type: cash crops	-6.16e-02	7.38e-03	-8.352	<2e-16***
Organic farming	9.12e-01	2.72e+01	0.034	0.9732
share of area covered with erosion prone crops (farm)	-4.07e-01	2.48e-02	-16.416	<2e-16***
number of crop rotation elements	-1.48e-01	1.36e-02	-10.877	<2e-16***

*** significant on 0.001 level
** significant on 0.01 level
* significant on 0,05 level

Log-likelihood: 1,416
Wald-statistic: 1,122
p-value: < 2.22e-16
Pseudo-R^2 = 0.3775376

4. Discussion and Conlusion

It is common to apply DEA for economic and environmental aspects in agriculture at farm level. This study goes one step further; by combining DEA and GIS it produces results on plot level and therefore allows a site-specific analysis. This is especially necessary in the case of environmental aspects, where a simple view at farm level is often not sufficient: therefore our method enables one to detect whether environment-friendly land use coincides with high-nature value areas.

Looking at the results, the maps show that in all cases (economy and environment aspects on grassland and arable land) there is no pattern with hotspots of extremely low resp. high efficiency scores visible. But one has to be aware that grassland and arable land in the study region is quite homogenous. In a more unequal region, one might expect different results. DEA efficiency-scores second-stage analysis shows that variables expressing the site quality, as well as variables expressing farm management, have a significant impact on efficiency scores. Nevertheless, the farm characteristics have a higher influence on efficiency scores. This seems logical, since the question of how to cultivate a single plot depends greatly on farm organisation. For instance, cash-cropping farms have to consider crop-rotation restrictions. Husbandry farmers are even more restricted in their choice of cultivation as land primarily serves for fodder production for breeding. Consequently, these farmers have to produce a certain amount of fodder and hence have almost no production alternatives on a single plot.

From the point of view of data collection, one can say that it is difficult to derive plot-specific data, since economy-oriented data in particular refers to farm level and has to be disaggregated to plot level. The influence of this procedure on the results cannot be determined in this study, but there might be a non-negligible influence on the results. On the other hand, we use plot-specific data such as site quality, planting and yield estimations. Consequently, the economic- as well as the environment-oriented efficiency scores clearly depend on plot- specific factors. This becomes obvious when considering the results of the second-stage DEA Tobit regression. Most of the site specific variables have a significant influence on economy- and environment-oriented efficiency scores. Site quality determines about 12 % of the overall variability of the efficiency scores.

Finally, one should note that some authors challenge the use of a Tobit-regression in two-stage DEA analysis, instead of which they recommend using a standard OLS model (cf. McDonald, 2008). Consequently, we applied a linear model and came to the conclusion that it confirms our results. Coefficients show the same sign and magnitude, significance is almost identical and R^2 is in accordance with our Pseudo

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ANNEXE I: ESTIMATION OF PROFIT AT SINGLE-PLOT LEVEL

Figure 6. Estimation of plot-specific income.

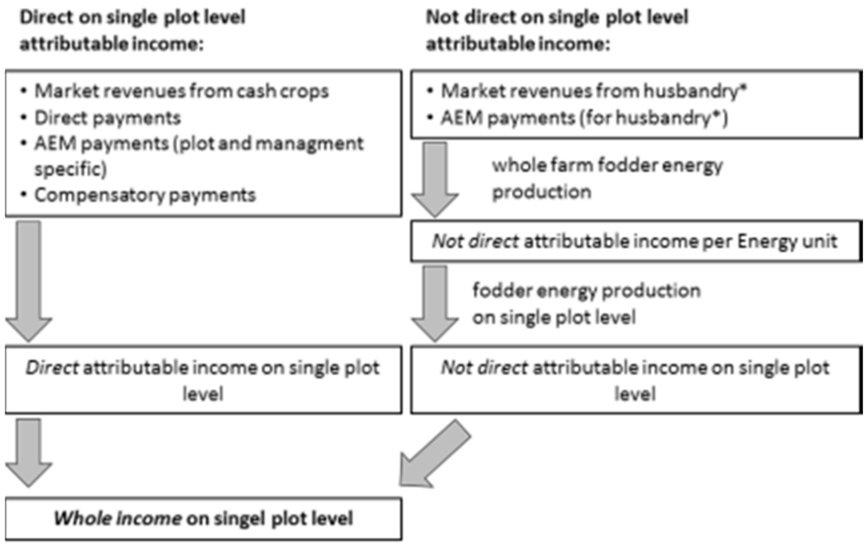
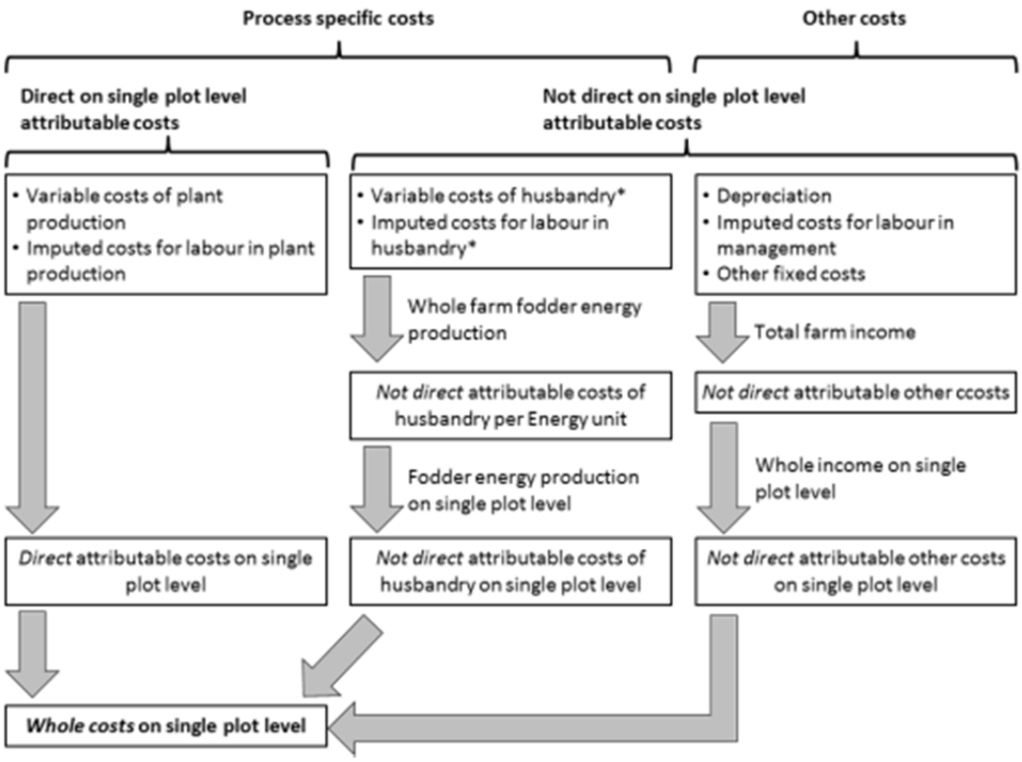


Figure 7. Estimation of plot-specific costs.



ANNEXE II: ESTIMATION OF NITROGEN FERTILIZATION

The derivation of variable $Ndem_{FID}$(total nitrogen demand) for each single plot is done via the nitrogen requirement of crops cultivated and the respective yield level.

$$Ndem_{FID} = \sum A_{FID} \times (Sh_{PV} \times Y_{PV,FID} \times cN + \begin{cases} 30\ wennif(PV <> Legume\ or\ ext.grassland \\ 0\ other \end{cases} \quad (4)$$

$Ndem_{FID}$	N-demand of plot in kg
Sh_{PV}	share in type of crop production on the total area of field plot
A_{FID}	area of field plot in ha
$Y_{PV,FID}$	yield of production method on field plot in dt/ha; $Y_{PV,\ FID}=f$ *(LSK, yield statistics)*
cN	N-content in harvest in kg N / dt (for legumes N from symbiotic N-fixation is accounted for)
PV:	Type of crop

$$orgNsup_{FID} = \frac{orgNsup_{BNR} \times A_{FID}}{A_{BNR}} \quad (5)$$

orgNsupFID	organic N-supply in kg
A_{BNR}	area of farm in ha

$$orgNsup_{BNR} = \sum Q_{Hus} \times orgN_{HUS} \times (1 - SL) \quad (6)$$

$orgNsup_{BNR}$	organic N-supply in kg of the farm
Q_{Hus}	quantity husbandry each animal species, yearly average
$orgN_{HUS}$	organic N from husbandry per LU in kg
SL	storage loss (15 %)

$$minNsup_{FID} = \begin{cases} 0\ if\ organically\ farmed\ or\ orgNsup_{FID} \times (1 - FL) \times OR > Ndem_{FID} \\ Ndem_{FID} - orgNsup_{FID} \end{cases} \quad (7)$$

$minNsup_{FID}$	mineral N-supply on field plot
FL	field loss (10 %)
OR	occupancy rate (plant availability) org. N (70 %)

The $\mathrm{Ndem_{BNR}}$ (N-demand) of each farm was calculated as in Formula (8).

$$Ndem_{BNR} = \sum Ndem_{FID} \quad (8)$$

$Ndem_{BNR}$	N-demand of farm in kg

The remaining emissions of nitrogen to the soil, groundwater and surface water, as well as into the air, are taken into account in the form of a static loss rate. This also includes losses in the form of ammonia. The biological nitrogen fixation by legumes and the atmospheric deposition are disregarded for the calculation, in particular, since atmospheric deposition of nitrogen results partly from the non-agricultural sector.

$$Nsup_{FID} = minNsup_{FID} + orgNsup_{FID} \quad (9)$$

$Nsup_{FID}$	N-supply in kg on field plot