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# Distributional Impacts of Cost-effective Spatially Homogeneous and Regionalized Agri-Environment Payments. A case study of a Grassland Scheme in Saxony, Germany

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## Abstract:

Economic analysis of agri-environment schemes (AES) has focused mainly on improving their cost-effectiveness. In contrast, the distributional impacts of AES have received less attention in the economic literature, even though the implementation of cost-effective policies can receive much more support, if their distributional impacts are desirable. We combine cost-effectiveness and distributional considerations and investigate empirically for a case study (a grassland program in Saxony, Germany), if trade-offs or synergies exist between improving the cost-effectiveness of an AES and its distributional impacts. We apply an ecological-economic modelling procedure to design two cost-effective AES - one scheme with spatially homogeneous payments and one with regionally differentiated payments. To compare the distributional impacts of the schemes we use the criteria of equality, equity and Rawls' maximin criterion. Our results suggest that substantial cost-effectiveness improvements can be achieved with the spatially differentiated AES. Regarding distributional impacts, on the federal state level and within the largest region, we find a trade-off between equality and cost-effectiveness, whereas equity generally increases with improved cost-effectiveness of the AES, except in the largest region. On Rawls' maximin criterion the spatially homogeneous payments are preferred, as they lead to the highest net benefits in the poorest region. This shows the importance of analyzing the distributional implications of cost-effective AES on different spatial levels.

Keywords: cost-effectiveness, distribution, fairness, maximin, agri-environmental payments, ecological-economic modelling, spatial differentiation

# 1 Introduction

Agri-environment schemes (AES) aim to support land use measures of farmers that are costly to them but beneficial to biodiversity, the environment or the landscape. AES can be found in most developed countries. Examples of AES include the Conservation Reserve Program (CRP) in the US (Claassen et al., 2008), the Agri-environmental Grassland Premium in France (Buller and Brives, 2017), the Agri-environmental, Climate Change and Animal Protection Program in Baden-Württemberg, Germany (Ministry of Rural Affairs, Food and Consumer Protection Baden-Wuerttemberg, 2016), and the Australian National Landcare Program (Robins, 2018). AES exist also in some developing countries (e.g. the Sloping Land Conversion Program (SLCP) in China (Lu and Yin, 2020) where they are usually referred to as Payments for Ecosystem Services (PES).

A large part of the economic analysis of AES has focused on how to improve their cost-effectiveness (Ansell et al., 2016), here understood as how to design AES so that for available financial resources environmental aims are achieved to the greatest possible extent (Wätzold and Schwertner, 2005). Regarding the design of cost-effective AES, the spatial optimization of schemes has become a key concern (Engel, 2015), especially with respect to schemes targeted at the conservation of biodiversity (Hanley et al., 2012). Four main threads of discussion can be distinguished: The first thread analyzes possible improvement in cost-effectiveness through 'benefit-cost targeting' which is normally superior to only (environmental) benefit or cost targeting strategies (Babcock et al. 1996), but can be less cost-effective when there is a considerable output price effect (Wu et al., 2001). The second thread investigates incentives to provide spatially aggregated (Parkhurst et al., 2002) or evenly allocated conservation areas (Bamière et al., 2011). A focus has been on analyzing the cost-effectiveness of payment designs such as the agglomeration bonus and the agglomeration payment schemes to provide spatially aggregated habitats (Drechsler et al., 2016; Lewis et al., 2011; Wätzold and Drechsler, 2014). The third line of discourse focuses on the spatial scale of habitat conservation in general. It is suggested that depending on the different types of species the appropriate management scale differs (Ekroos et al., 2016), e.g. landscape-scale conservation management is considered more cost-effective than farm-scale management in the case of ecosystem services provided by mobile species, which require a spatial habitat pattern on larger scale (Cong et al., 2014). The forth thread is based on the idea of spatially differentiated payments. If cost and benefit functions differ among regions, a payment scheme that includes regionally differentiated payments is likely to be more cost-effective than a scheme with homogeneous payments across regions (Wätzold and Drechsler, 2005). In an empirical analysis of different hypothetical AES to conserve birds in the Peak District in England, Armsworth et al. (2012) identified substantial cost-effectiveness gains of a spatially differentiated payment scheme albeit at the expense of substantial transaction costs.

In contrast to cost-effectiveness considerations, the distributional impacts of AES have received less attention. Wu and Yu (2017) investigate cost-effectiveness equity trade-offs using the CRP as a case study. They find that the CRP is quite cost-effective, but not very equitable on most indicators used, even though large part of the fund goes to lower-income counties. Claassen et al. (2001) also analyze trade-offs in the design of AES. Using hypothetical scenarios, they investigate spatial distribution of gains and losses from the implementation of a policy for reducing water quality damage due to sediments. They conclude that reaching two goals, e.g. environmental improvement and farm income improvement, with one policy is hardly possible. This finding is in line with Uthes et al. (2010) who suggest that having rural development as a goal undermines achieving environmental benefits and cost-effectiveness of AES. By contrast, Gauvin et al. (2010) demonstrate that for the SLCP targeting parcels, which maximize jointly the environmental and poverty alleviation benefits is only slightly less cost-effective than the most cost-effective strategy of selecting parcels with the highest benefit–cost ratio. Similarly, Mouysset (2014) finds that when ecological objectives are low or high grassland management subsidies in France can reach simultaneously ecological and social objectives (increasing minimum farmer income) and at the same time minimize welfare losses.

This paper investigates cost-effectiveness gains from a hypothetical regional differentiation of an AES in Saxony, Germany, and the resulting distributional impacts. By this, we contribute to the above-mentioned discussions in two ways. (1) Similarly to Armsworth et al. (2012), we empirically investigate the cost-effectiveness gains of spatially differentiated payments over spatially homogeneous payments. In contrast to Armsworth et al. (2012), however, the additional transaction costs of our proposed differentiated scheme are negligible as we do not suggest introducing a different scheme but just to pay farmers in different Saxon regions differently for the same measures. (2) By analyzing the distributional impacts of the spatial differentiation of the Saxon AES, we also contribute to the debate on trade-offs and synergies between cost-effectiveness and distributional impacts of AES.

Our case study is an AES focused on grassland biodiversity in the federal state of Saxony, Germany (in the following referred to as Saxon AES). We modify the ecological-economic modelling procedure from Wätzold et al. (2016) in order to design a cost-effective regionalized scheme and take into account distributional impacts of AES. We investigate the cost-effectiveness gains (measured in habitat improvements for 13 bird species, 14 butterfly species and 7 habitat types for given budgets) of an optimized AES with homogeneous payments for the whole of Saxony and an optimized AES with payments differentiated according to three Saxon agri-economic regions in comparison to the Saxon AES. Finally, we analyse the distributional impacts of the Saxon AES with the distributional impacts of the two cost-effective alternatives, based on the principles of equality and equity/accountability (Ohl et al., 2008) and Rawls' (1999) maximin criterion.

# 2 Case study

## 2.1 Agriculture in Saxony

About half of the total area of the German federal state of Saxony (49.2%=9,066 km²) is used for agriculture with approximately 20% (1,850 km²) of the overall agricultural area being grassland (Saxon State Ministry of the Environment and Agriculture, 2014b). Saxony is divided into three agri-economic regions (Figure 1), each of which covers areas with similar physio-geographic characteristics.

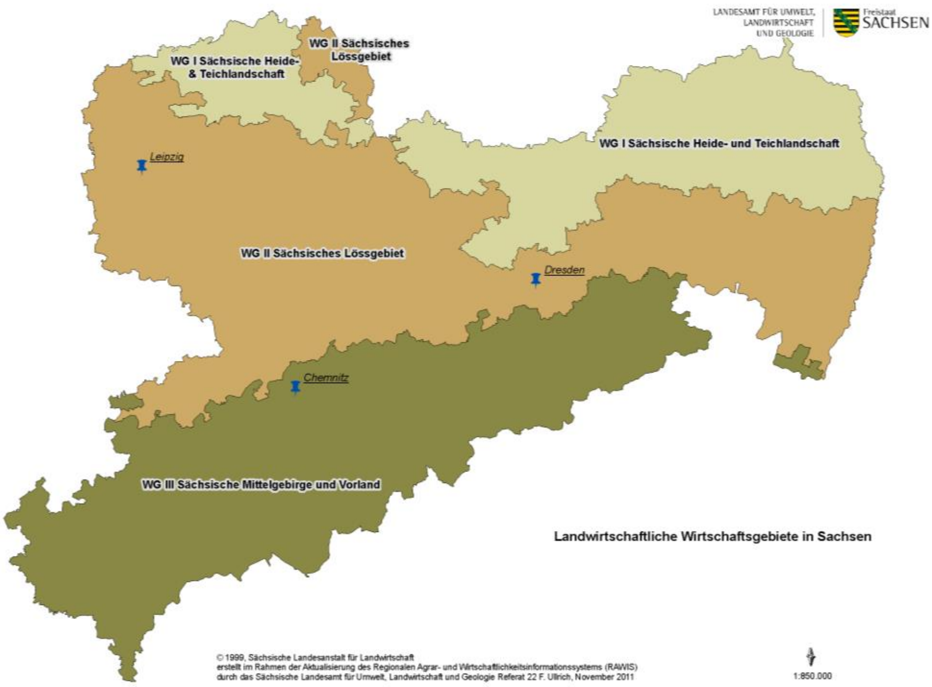


Figure 1 Agri-economic regions in Saxony. 1 = WG I Sächsisches Heide- und Teichlandschaft (Saxon Heath and Pond Landscape), 2 = WG II Sächsisches Lößgebiet (Saxon Loess Region), 3 = WG III Sächsisches Mittelgebirge und Vorland (Saxon Uplands and Foothills). Source: modified representation based on data and with the permission of the Saxon State Office for the Environment, Agriculture and Geology (2014).

These agri-economic regions include the Saxon Heath and Pond Landscape (Sächsisches Heide- und Teichlandschaft), the Saxon Loess Region (Sächsisches Lößgebiet) and the Saxon Uplands and Foothills (Sächsisches Mittelgebirge und Vorland), referred to as region 1, region 2 and region 3 in the following. Starting from 100 m above sea level in the north lowland, the altitude continually rises to the south and east to approximately 900 m. Altitude is the main factor that leads to differences in climatic conditions and vegetation types in the different regions (Saxon State Institute for Agriculture, 1999). The soil productivity (expressed as grassland number[1]) is on average best in region 2 (Table 1). Regions 1 and 2 include much less grassland area than region 3 (Corine Land Cover, CLC, 2000, see Mewes et al., 2012).

For our analysis we consider farms with a relatively high percentage of grassland area which are likely to participate in a grassland AES (e.g. cattle and dairy farms, see AppendixAppendix B for relevant farms according to the Farm Accountancy Data Network).

Table 1 Comparison of the analyzed grassland farms in the three agri-economic regions of Saxony.

| **Region** | **Region 1** | **Region 2** | **Region 3** |
|---|---|---|---|
| Number of farms[a] | 33 | 131 | 197 |
| Average grassland number[b] | 38 | 48 | 35 |
| Range grassland number[b] | 17-56 | 32-71 | 13-62 |
| Grassland area used for modelling in ha[c] | 47,844 | 69,206 | 121,088 |
| **Mean operating income in €/ ha**[a] | **812** | **1,149** | **910** |
| Mean operating income in €/ ha as percent of region 1[a] | 100.00% | 141.50% | 112.07% |
| **(gross operating surplus+ personnel costs in €)/ full time worker**[a] | **31,300** | **38,293** | **32,231** |
| (gross operating surplus + personnel costs in €)/ full time worker as percent of region 1[a] | 100.00% | 122.34% | 102.97% |

Sources: [a] Source: Saxon State Ministry of the Environment and Agriculture (2014a), own calculation based on surveyed farms.
[b] Source: Representation based on data and with the permission of the Saxon State Office for the Environment, Agriculture and Geology (2014), own calculation.
[c] Source: based on Corine Land Cover, CLC, 2000 (see Mewes et al. 2012).

[1] The grassland number (GZ) (ranging from 1 to 100) is a measure of the productivity of grassland in Germany and indicates the percentage yield ratio of a certain grassland area to the best soil. It depends on many different factors, such as soil type, climate, moisture, and relief (Soil Estimation Act, 2007, Germany).

In data provided by the Saxon State Ministry of the Environment and Agriculture (2014a), we find altogether 33 relevant farms in region 1, 131 farms in region 2 and 197 farms in region 3 (Table 1). The actual number of farms is higher, since not all farms participated in the agricultural data collection survey. However, the data provided in Table 1 can be considered representative in terms of differences between regions 1-3.

To identify the poorest region, we would ideally use individual farm income data. However, due to a lack of data on the farm level, we compare only the mean incomes of the three regions and define the region with the lowest mean income as the poorest region. A key indicator for the regional comparison of income is "gross operating surplus plus personnel costs per full time worker". This indicator is used in official statistics to indicate the sustainable disposable income per full time worker and is not directly dependent on the number, size, and legal forms of farms in the regions (Saxon State Ministry of the Environment and Agriculture, 2014a). On this factor, the income in region 2 is 22% higher than the income in region 1 and the income in region 3 is only slightly higher than in region 1 (3%). The mean operating income per hectare in region 2 is even 42% higher than that in region 1, which corresponds to the high soil productivity in region 2. The mean operating income per hectare in region 3 is 12% higher compared to region 1. In sum, both indicators suggest that income is substantially higher in region 2 than in the other two regions and it is only slightly higher in region 3 than in region 1.

### 2.2 Conservation challenge and Saxon grassland scheme

As in many other parts of Europe, since the 1970s agricultural intensification and amelioration has led to a loss of grassland types resulting in uniform grasslands in Saxony (Bastian et al., 2002, Klimek et al., 2007). This has resulted in a general loss of biodiversity and the endangerment of many grassland species such as meadow birds and butterflies (Bastian et al., 2002, Wätzold et al., 2016). To reverse this trend and support extensive grassland management, the federal state of Saxony has implemented AES for grassland.

Between 2007 and 2014 the AES pertaining to grassland in Saxony was the programme "Extensive grassland use, nature conforming grassland management and conservation" ("Extensive Grünlandwirtschaft, Naturschutzgerechte Grünlandbewirtschaftung und Pflege" - Saxon State Ministry of the Environment and Agriculture, 2015). The scheme comprised eight different mowing and grazing measures and four other measures (e.g. transformation of arable land into grassland and the impoverishment of grassland soils). We focus on the mowing and grazing measures (Table A. 1 provides details of these measures) because they can be analyzed by the ecological-economic modelling procedure applied in our analysis. The payments per hectare, the size of participating area and the total budget spent on the measures in 2013 are used as inputs for the simulation of the Saxon grassland AES with the ecological-economic modelling procedure.

## 3 Ecological-economic modelling procedure

For our analysis, we apply the ecological-economic modelling procedure from Wätzold et al. (2016) to analyze the effectiveness and cost-effectiveness of grassland AES and modify it in order to analyze cost-effectiveness gains from regionalization and its distributional impacts. The following section provides a brief overview of the modelling procedure. For a detailed description, we refer to Wätzold et al. (2016). The ecological-economic modelling procedure consists of several components, which are depicted in Figure 2. Different species and grassland measures with their characteristics as well as landscape parameters are used as inputs for the calculation of the costs of different grassland measures (in the agri-economic cost assessment) and their ecological effects on the selected species (in the ecological model). These results can be used for simulation or optimization of an AES. We further modified the modelling procedure to employ the results of the simulation and optimization for the analysis of the regionalization and the distributional aspects. The next sections provide an overview of the modelling procedure, which is implemented in the decision support software *DSS-Ecopay* (see Sturm et al., 2018 for details on the software).

### 3.1 Conservation aims, land-use measures and landscape information

For Saxony, the procedure considers altogether 13 bird species, 14 butterfly species and 7 habitat types (Table A. 2) all of which are threatened or endangered. Information about certain characteristics of the species and habitat types related to the impact of grassland measures is available which is used as input in the ecological model. Altogether 475 different mowing regimes, grazing regimes and combinations of mowing and grazing regimes are included as land-use measures in the procedure. Mowing regimes differ in terms of the frequency and timing of mowing, restrictions regarding N-fertilizer input and the existence of mowing strips. Grazing regimes differ in terms of the beginning and length of the grazing period, the livestock density and the type of livestock. Regime combinations of mowing and grazing vary in terms of timing of mowing, start of grazing, stocking rate and type of livestock (see Wätzold et al., 2016 for details).

Landscape information (e.g. altitude, land use, land productivity, soil moisture) is available on the level of grid cells (pixels) with a resolution of 250m x 250m=6.25 ha and is used as input in the ecological model and the agri-economic cost assessment.

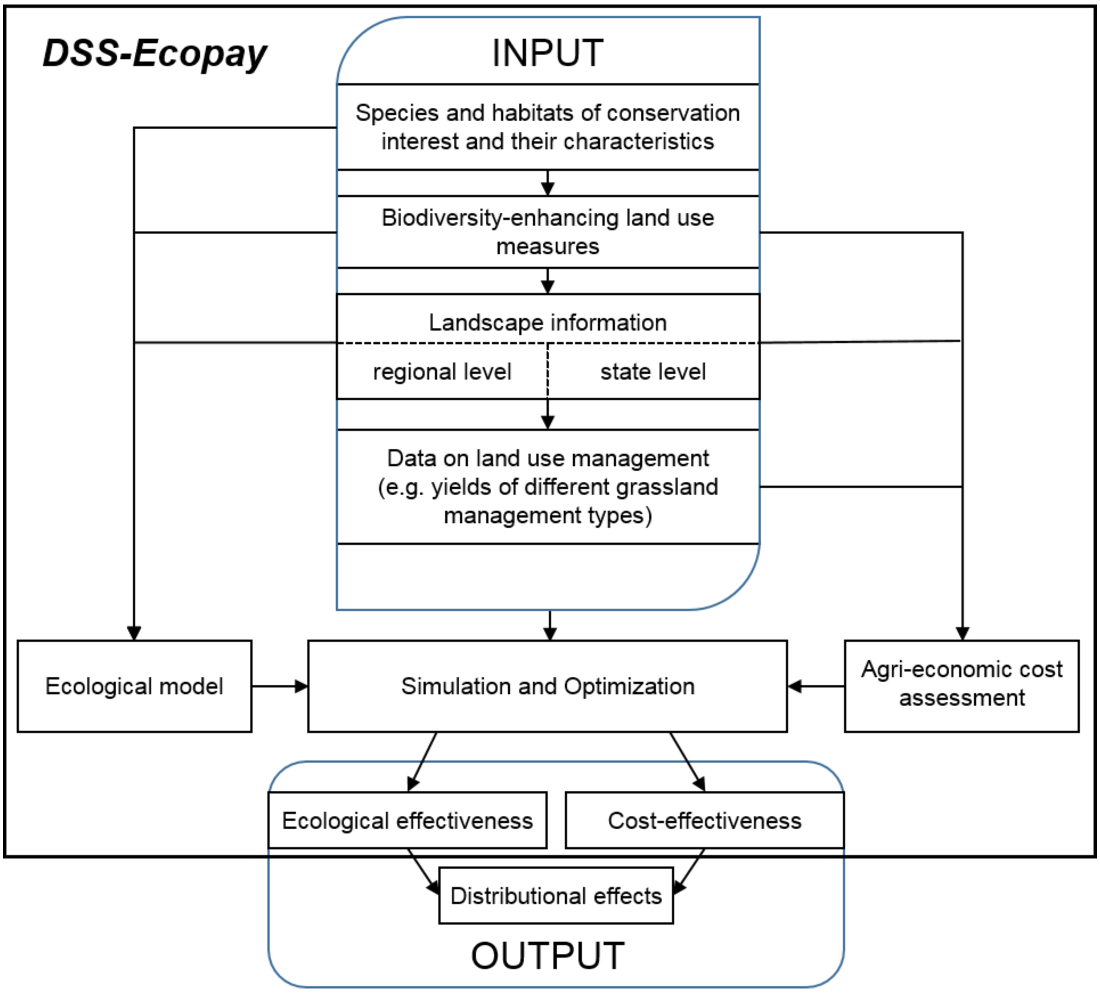


Figure 2 Components of the ecological-economic modelling procedure. Source: modified from Wätzold et al. (2016).

### 3.2 Ecological model

The ecological model evaluates the impacts of the different measures on the different species and habitat types in a spatially differentiated manner, i.e. differentiated for each grid cell (Johst et al., 2015 provides a detailed description of the ecological model). The effect of land use measures on species and habitat types is measured in terms of the habitat quality on each grid cell. This local habitat quality shows the suitability of the habitat for the reproduction of the species and can take values between 0 (reproduction is not feasible on a grid cell) and 1 (maximum habitat quality for the reproduction of a species on a grid cell). The ecological model estimates for each grid cell $l$ the local habitat quality $q_j^{l,m}$ resulting from a measure $m$ at timing $t_m$ and the overall achieved effective habitat area $A_j^{eff}$ for a species $j$ (see Eq. 1).

The $A_j^{eff}$ is calculated by summing up the area of all grid cells in the landscape multiplied with their local habitat quality $q_j^{l,m}$, under the condition that the measure $m$ results in a habitat quality higher than a predefined minimum habitat quality $q_j^{min}$ for a species, which is set to 0.1 for butterflies and 0.3 for birds and habitat types based on expert knowledge (cf. Wätzold et al., 2016).

$$A_j^{eff} = \sum_{l(r_j;\, q_j^{l,m}(t_m) > q_j^{\min})} A^l \cdot q_j^{l,m}(t_m) \qquad \text{Eq. 1}$$

where $A^l = 6.25$ ha represents a grid cell.

The occurrence and dispersal rate of a species are accounted for in the calculation of habitat quality by summing up only grid cells that contain a species or are within a certain radius of dispersal ($r_j$). For birds this radius is assumed to be infinite, due to their good dispersal ability, whereas for butterflies $r_j$ is specified for each species based on expert knowledge. In the ecological-economic modeling procedure, the effective habitat area $A_j^{eff}$ is the indicator for the ecological effect of a land use measure $m$ on a species $j$ on the regional scale and is used to assess the ecological effectiveness of a measure. The higher the effective habitat area $A_j^{eff}$, the more effective is the measure.

### 3.3 Agri-economic cost assessment

The agri-economic cost assessment estimates the costs of the different measures spatially differentiated for each grid cell. Due to data access restrictions, the ecological-economic modelling procedure does not rely on individual farm data, but considers grid cells instead. That is, in the modelling procedure, one grid cell stands for one virtual farmer. Farmers are assumed to maximize their profits. Thus, a farmer (grid cell $l$) participates in an AES and adopts a measure $m$, if the payment $p_m$ at least covers his costs of participating in the scheme.

$$p_m \geq c^{l,m}(t_m) + tc \qquad \text{Eq. 2}$$

where $tc$ represents the transaction costs of the farmer to participate in a scheme, arising from e.g. paperwork and communication with authorities, and $c^{l,m}(t_m)$ the opportunity costs of the farmer for not being able to carry out the profit-maximizing grassland use. The opportunity costs depend on the yield loss as well as changes in variable and labor costs, which, in turn, depend on the timing $t_m$ of the land use measure *m*. Mewes et al. (2015) provides a thorough explanation of the agri-economic cost assessment.

### 3.4 Simulation of an AES

The ecological-economic modeling procedure can simulate the effects of an AES on species and habitat types. In the procedure, an AES is defined by a single or a combination of land use measures *m*, a corresponding payment $p_m$ (per year and ha) for each measure, and a maximum area of implementation $A_m^{max}$ for each measure. For the simulation of the Saxon AES the $A_m^{max}$ was defined as the size of the area on which a specific measure was applied in 2013 (Table A. 1.).

If a farmer can select between different measures, the farmer (grid cell) is assumed to adopt the measure with the highest difference between payment and participation costs, i.e. the measure with the highest producer surplus $PS^{l,m}$, as long as it is positive ($PS^{l,m}>0$) and the maximum participating area $A_m^{max}$ for the measure has not been reached.

$$max: \ PS^{l,m} = p_m - (c^{l,m}(t_m) + tc) \qquad \text{Eq. 3}$$

For technical details of the simulation we refer to Wätzold et al. (2016). The result of the simulation is a particular land use pattern characterized by measures and payments assigned to grid cells and habitat quality for each species in each participating grid cell. The ecological effectiveness of an AES is assessed by calculating $A_j^{eff}$ for each species and grassland type. The total budget *B* for an AES is the sum of the products of the payments $p_m$ for each measure with the size $A_l = 6.25$ ha and number $N_m$ of grid cells where this measure is applied:

$$B = \sum_m p_m N_m A_l \qquad \text{Eq. 4}$$

### 3.5 Cost-effectiveness analysis

The cost-effectiveness analysis in the modelling procedure can be done in two ways; minimization of a budget for given conservation goals and maximization of goal attainment under a budget constraint, $B_0$. Here, we focus on the latter option, i.e. to maximize the total effective habitat area $A_{tot}^{eff}$ for a number of predefined species with a given budget.

$$A_{tot}^{eff} = \sum_j w_j A_j^{eff} \rightarrow \max \qquad \text{subject to } B \leq B_0 \qquad \text{Eq. 5}$$

The formula above can reflect a decision-maker's preferences for the protection of certain species through the insertion of weights $w_j$. Here, we give equal weights to all 34 species and habitat types identified for Saxony as they are all protected.

Since the core topic of the paper is the cost-effectiveness gain of regional differentiation of an AES and related distributional impacts, in the optimization we consider only the land use measures from the Saxon AES (by contrast Wätzold et al. (2016) use a pool of 58 best-candidate measures). The optimization is carried out with simulated annealing and maximizes the ecological effectiveness of the Saxon AES under the given overall budget constraint from the simulation. The result of the optimization is a cost-effective AES, i.e. a set of land use measures with the corresponding payments per ha, the area covered by each measure, the budget required, as well as the effect on the different species and habitat types $A_j^{eff}$.

To compare the cost-effectiveness of the different schemes, we use $Eff_{type}$, which is the effective habitat area $A_{type}^{eff}$ for each species *type* (i.e. for *birds*, *butterflies*, *habitat types* or *all* species) per Euro budget $B_{type}$ spent:

$$Eff_{type} = \frac{A_{type}^{eff}}{B_{type}} \qquad \text{Eq. 6}$$

This indicator taken for all species together $Eff_{all}$, i.e. based on the total effective habitat area $A_{tot}^{eff}$, should be discussed with caution, since due to their much higher dispersal radius the conserved areas for bird species ($A_{birds}^{eff}$) tend to be much higher than for butterflies ($A_{butterflies}^{eff}$). We therefore make some general comparisons based on all species, but also point to the differences in cost-effectiveness for the different species types.

### 3.6 Regionalization

To investigate the cost-effectiveness of regionalization, the modelling procedure is modified in the following way. GIS data on the spatial distribution of agri-economic regions (from Saxon State Office for the Environment, Agriculture and Geology, 2014) has been added as an input to the model. Thus, the existing pixels are attributed to the three regions (pixels which cross the border between two regions are excluded). For each region, we calculate the budget spent in the simulation of the Saxon AES. The resulting regional budgets are then used in separate optimizations of the payments for the three regions to ensure comparability with the simulation results. For each region, the ecologic-economic modelling procedure maximizes the ecological benefit under the given budget constraint.

### 3.7 Distributional impacts analysis

We use the results of the modelling procedure to compare the distributional impacts of the Saxon AES, the optimized and the regionally optimized AES. The comparison is based on three fairness principles: equality, equity and maximin.

According to the equality principle (based on Konow, 2003; Leventhal, 1980) individual opportunities, rights, proportions etc. should be equal. In the case of AES, we concentrate on the egalitarian view of equality of outcomes (Pascual et al., 2010), i.e. compensations in AES should be equal for all farmers. This corresponds to the distribution of equal payments ($P$).

The equity principle or accountability principle (Homans, 1974; Konow, 2003) stipulates that a fair output distribution should be in proportion to an individual's input or effort. In AES equity translates to compensations that are in accordance to the individual conservation efforts of the farmers, i.e. to their opportunity costs (Ohl et al., 2008). This relates to the distribution of producer surplus ($PS$), which is the difference between the received payments and the incurred opportunity costs. Therefore, we associate higher equity with a more equal distribution of $PS$.

The maximin principle introduced by Rawls (1999, p. 266) states that: "Social and economic inequalities are to be arranged so that they are … to the greatest benefit of the least advantaged". In the context of PES, this principle has been interpreted by Pascual et al. (2010) as maximizing "the net benefit to the poorest landholders". As we are unable to identify single farm income, we assume that a farmer in region 1 - the region with the lowest income expressed as "gross operating surplus plus personnel costs per full time worker" – is "poorest". The net benefit in our case corresponds to the PS of the farmers. When comparing the schemes based on the maximin principle we investigate in which scheme the $PS_{min}$, $PS_{mean}$ and $PS_{sum}$ in the "poorest region" - region 1 - are highest. Due to data limitations and asymmetric information between the farmers and the regulator about the farmers' costs, in practice a pro-poor scheme may not concentrate explicitly on the $PS$ of the poorest farmers, but just try to allocate higher payments to poorer participants. Therefore, in our analysis based on the maximin principle, in addition to the comparison of $PS$, we also investigate in which scheme the payments (i.e. $P_{min}$, $P_{mean}$ and $P_{sum}$) in the "poorest" region 1 are highest.

In order to analyze the equality of the simulated and optimized AES for Saxony on a federal state and regional level, we compare the payment distributions, and for analyzing the equity of the schemes we compare the producer surplus distributions among pixels as a proxy for farmers.

Both comparisons are based on the Atkinson index (Atkinson 1970), with Whitehouse (1995) defining the Atkinson index (AI) as a measure of income inequality as follows:

$$AI(\varepsilon) = 1 - \left(\frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i}{\bar{y}}\right)^{(1-\varepsilon)}\right)^{\frac{1}{1-\varepsilon}}, \qquad \text{for } \varepsilon \neq 1 \qquad \text{Eq. 7}$$

$$AI(1) = 1 - \prod_{i=1}^{n}\left(\frac{y_i}{\bar{y}}\right)^{1/n}, \qquad \text{for } \varepsilon = 1 \qquad \text{Eq. 8}$$

where $y_i$ refers to the individual income and $\bar{y}$ refers to the average income of individuals in a population of size $n$.

In our case, $y_i$ stands for payment (*P*) respectively producer surplus (*PS*), and $\bar{y}$ corresponds to the average payment or producer surplus. The Atkinson index takes values from 0 to 1, the lower the value, the more equal (or in our case equitable) the distribution, whereby perfect equality/equity corresponds to a value of 0 for the Atkinson index.

The calculation of the Atkinson index is based on a parameter epsilon ($\varepsilon$), which can reflect different levels of inequality/inequity aversion and thus different social welfare preferences. The higher the value of $\varepsilon$, the stronger the inequality/inequity aversion, with $\varepsilon = 0$ corresponding to no interest in the distribution and high values of $\varepsilon$ corresponding to high inequality/inequity aversion and Rawlsian preferences. In accordance with Schlör et al. (2013) the $\varepsilon$ parameter can reflect preferences for equality (in our case also equity) and efficiency and can be defined as a ratio between an equality/equity parameter $\alpha$ and an efficiency parameter $\beta$, where these parameters can each take values between 1 and 5:

$$\varepsilon = \frac{equality/equity}{efficiency} = \frac{\alpha(1,2,3,4,5)}{\beta(1,2,3,4,5)} \qquad \text{Eq. 9}$$

Thus, $\varepsilon$ ranges from 0.2 with low inequality/inequity aversion and strong efficiency preferences to 5 with high inequality/inequity aversion and Rawlsian preferences. With higher values of $\varepsilon$ the Atkinson index becomes more sensitive to income inequalities, in our case – to payment or producer surplus inequalities. The special case of $\varepsilon = 1$ refers to social preferences attributing equal weights to equality (in our case also equity) and efficiency and we employ this assumption in our calculations.

We transform the values of the Atkinson (AI) index by defining *EP* as a measure of equality and *EPS* as a measure of equity with higher values indicating more equal/equitable distributions, where:

$$EP = 1 - AIP(\varepsilon = 1) = 1 - \prod_{i=1}^{n} \left(\frac{P_i}{\bar{P}}\right)^{1/n}$$ Eq. 10

$$EPS = 1 - AIPS(\varepsilon = 1) = 1 - \prod_{i=1}^{n} \left(\frac{PS_i}{\overline{PS}}\right)^{1/n}$$ Eq. 11

Here *i* refers to pixels instead of individuals or farmers, due to the mentioned limitations of data accessibility. Using these measures of equality/ equity we compare the Saxon AES and the optimized schemes based on the equality and equity principles.

# 4 Cost-effectiveness results and analysis

## 4.1 Overview of results

***Simulation***

We find that the Saxon AES contributes considerably to the conservation of endangered grassland birds, but fails to protect most of the butterfly species and habitat types (Figure 3 and Table A. 2). All bird species, except the crested lark, are conserved to some extent, whereas this applies only to five out of 14 butterfly species and four out of seven habitat types. All 10 measures from the Saxon AES are to some extent applied in regions 2 and 3, whereas in region 1 only nine measures are applied (an overview of the regionally differentiated results from the simulation and optimizations is found in Table A. 3)

***Statewide optimization***

Only seven out of the 10 measures in the Saxon AES are included in the statewide optimized scheme – five in region 1, three in region 2 and seven in region 3. Compared to the Saxon AES, the cost-effective AES leads to about 33% more $A^{eff}_{birds}$ and $A^{eff}_{habitats}$ (Table 2) whereas $A^{eff}_{butterflies}$ is a bit (16%) lower. The conservation levels of the optimized AES are higher for eight bird species, two habitat types, and one butterfly species. Overall, the optimized scheme generates effective habitat area for 11 birds, two butterflies and four habitat types.

***Regional optimization***

The regionalized cost-effective AES conserves overall 12 out of 13 bird species, six out of 14 butterfly species and three out of seven habitat types and includes all 10 measures from the Saxon AES (four measures in region 1, six measures in region 2 and all 10 measures in region 3). Despite a 13% lower budget, it leads for the whole of Saxony to a 61.23% larger $A^{eff}_{birds}$, 596.46% more $A^{eff}_{butterflies}$, and a 45.86% larger $A^{eff}_{habitats}$ than the Saxon AES (Table 2). The conservation levels are higher for most species and habitat types, except for the Garganey, the Snipe, alluvial meadows and lowland hay meadows. In comparison to the statewide cost-effective payment scheme, the effective habitat areas are 21% ( $A^{eff}_{birds}$), 729% ($A^{eff}_{butterflies}$), and 10% higher ($A^{eff}_{habitats}$) and the regionalized payments perform better for most species and habitat types, except the Corncrake, the Five-spot Burnet, alluvial meadows and lowland hay meadows (Table A. 2 and Figure 3).

Table 2 Regional comparison of the (cost-)effectiveness of the Saxon AES, the statewide and the regional optimizations.

| **Run** | **Regions** | $A^{eff}_{birds}$ **in ha** | $A^{eff}_{butterflies}$ **in ha** | $A^{eff}_{habitats}$ **in ha** | $A^{eff}_{tot}$ **in ha** | **Budget ($P_{sum}$) in Euro** | **Producer surplus ($PS_{sum}$) in Euro** |
|---|---|---|---|---|---|---|---|
| **Saxon AES** | region 1 | 28 755 | 0.65 | 1 225 | 29 981 | 2 104 425 | 1 258 621 |
| | region 2 | 47 273 | 15.26 | 816 | 48 105 | 2 905 838 | 1 498 020 |
| | region 3 | 78 702 | 29.66 | 1 763 | 80 495 | 6 129 313 | 4 467 608 |
| | **Saxony** | **154 731** | **45.58** | **3 805** | **158 581** | **11 139 575** | **7 224 249** |
| **as percent difference to simulation:** | | | | | | | |
| **statewide optimization** | region 1 | 96.63% | -100.00% | 5.86% | 92.92% | 11.40% | 74.97% |
| | region 2 | 66.92% | -13.31% | -100.00% | 64.06% | -3.30% | 105.73% |
| | region 3 | -9.93% | -14.42% | 113.77% | -7.22% | -5.03% | -34.95% |
| | **Saxony** | **33.36%** | **-16.05%** | **33.14%** | **33.34%** | **-1.48%** | **13.37%** |
| **regional optimization** | region 1 | 110.90% | -0.28% | -100.00% | 102.28% | -60.65% | -53.56% |
| | region 2 | 65.06% | -100.00% | -72.74% | 62.66% | -0.48% | 96.33% |
| | region 3 | 40.78% | 977.90% | 202.12% | 44.66% | -2.35% | -80.09% |
| | **Saxony** | **61.23%** | **596.46%** | **45.86%** | **61.02%** | **-12.88%** | **-38.89%** |

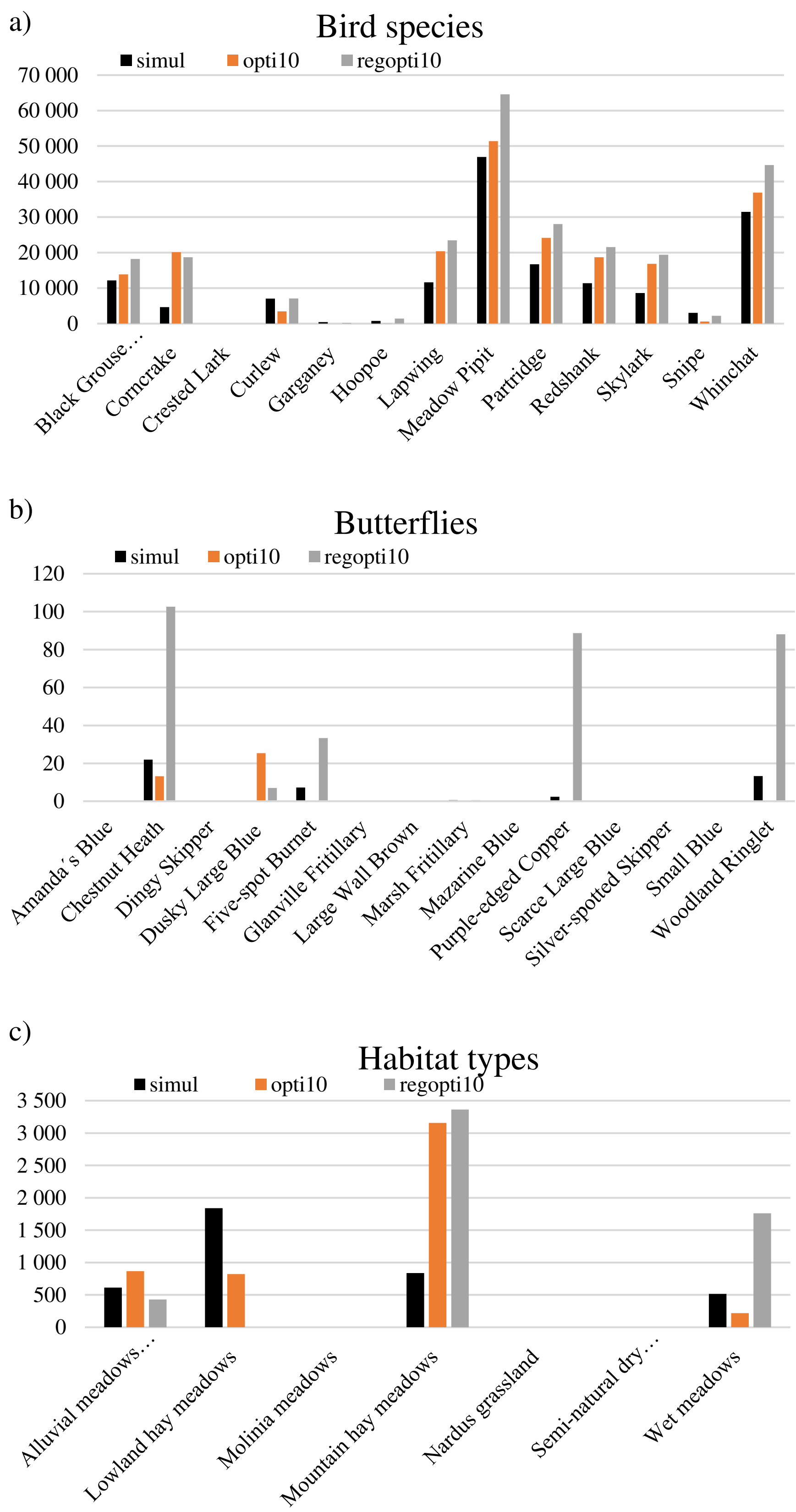


Figure 3 Comparison of the cost-effectiveness of the simulation (simul) with the statewide optimization (opti10) and regional optimization (regopti10) for birds (a), habitat types (b) and butterflies (c). The y-axis indicates the effective habitat area $A_j^{eff}$ achieved for each species in ha.

## 4.2 Analysis of results

In the analysis of the results, we focus on an explanation of why a regionalized payment scheme leads to cost-effectiveness improvements compared to the Saxon AES and the optimized Saxon AES with homogeneous payments. Generally, the optimization is able to identify cost-effective measures and induce their (increased) uptake for both optimized schemes. In both optimizations the participating area of the general mowing measures is reduced compared to the Saxon AES, due to their much lower benefit-cost ratios, whereas the participating area for 'mowing strips' and 'rotational grazing', the best-performing and lowest-cost measures, is increased. This mechanism can explain very well the increase in cost-effectiveness in the statewide optimization (33% more $A_{tot}^{eff}$ with nearly the same budget).

The regional optimization increases the overall cost-effectiveness further by taking advantage of cost differences between the three regions (Wätzold and Drechsler 2005). Payments are set lower in regions 1 and 3 with low opportunity costs than in region 2 with high opportunity costs (Table A. 3). By contrast, in the statewide optimization the payments are defined over the whole of Saxony and cannot take into account cost differences among regions. The rise in cost-effectiveness through regionalization comes only from the two regions with low opportunity costs (region 1 and 3); for region 2 with high opportunity costs, the regional optimization does not improve overall cost-effectiveness ($Eff_{all}$ in Table 3) further than the statewide optimized scheme. In this region both optimizations reduce substantially the number of measures and are therefore less effective and cost-effective for butterflies and habitat types than the Saxon AES. Thus, there are regional differences and the optimizations do not improve the cost-effectiveness for all different species types in all regions. However, on the federal state level the regional optimization is most cost-effective for all species types (highest $Eff_{type}$ values over Saxony for all species types in Table A. 4 in the appendix).

Additional cost-effectiveness improvements can arise in regionalization from the possibility to spatially focus payments relevant for the conservation of specific species, which occur only or mainly in one or several specific regions. In our study, this is particularly relevant for butterflies. The regional optimization generates substantially higher $A_{butterflies}^{eff}$, but only in region 3, which has the largest grassland area, low opportunity costs and in general most butterfly occurrence. In the regional optimization, all ten measures from the Saxon AES are applied in this region (Table A. 3) generating the diversity of grassland use needed to conserve different butterfly species (Johst et al. 2015, Wätzold et al. 2016). By contrast, in the statewide optimization due to the lower number of measures with mostly higher payments in all regions the cost-effectiveness for butterflies is even lower than in the Saxon AES.

In the other low-cost region 1 the overall cost-effectiveness is increased to a very high extent in the regional optimization by setting much lower payments and focusing only on four high benefit-cost measures. Thus, by aligning the payments and measures to the regional specifics, and offering much lower payments, the regional optimization is able to significantly improve the overall performance of the scheme in the two low-cost regions.

Interestingly, the resulting budgets in the regional optimizations are close to the budget constraints derived from the simulations in regions 2 and 3, but about 60% below the constraint in region 1. This large reduction in the budget results from lower payments, which lead to a situation where the available grassland area for mowing measures is utilized completely without reaching the budget constraint. The lower payments are feasible due to the lower land productivity in region 1 and the resulting lower cost of AES participation.

# 5 Distributional impacts and their relation with cost-effectiveness

In the analysis of distributional impacts, we use the measures introduced in section 3.7, the calculated values for which are presented in (Table 3). When we refer to the cost-effectiveness of the schemes in this section we consider the overall cost-effectiveness ($Eff_{all}$ in Table 3).

## 5.1 Comparison based on equality and equity principles

The Saxon AES has similar payment levels for all ten measures, the statewide optimization results in less measures with quite different payment levels, and the regional optimization leads to even more unequal payment distribution, due to the different levels of opportunity costs used as basis for the payments in the different regions. Thus, as expected, on the federal state level *P* are most equally distributed in the Saxon AES and least equally distributed in the regional optimization.

The statewide optimization is, in general, most equitable. There the *PS* is most homogeneously distributed, as the scheme includes less measures and aligns the homogeneous payments to the high opportunity costs in region 2 so that for each measure *P* are the same and the *PS* levels are similar for most of the measures (and pixels) involved. The regionally differentiated optimization leads to a less homogeneous distribution of *PS* than the statewide optimization and the Saxon AES because it reduces substantially the *P* and thus *PS* for measures in regions 1 and 3 with low opportunity costs, but the *P* and *PS* in region 2 with high opportunity costs remain higher. As in the regional optimization the farmers in region 2 do not compete with farmers with lower opportunity costs from the other regions, some of the less cost-effective mowing measures with high *P* and *PS* are included in the regionalized scheme in region 2, whereas these measures are not applied in this region in the statewide optimization.

Thus, on the federal state level optimized statewide payments lead to a trade-off between cost-effectiveness and equality (*EP*), but a synergy of cost-effectiveness and equity (*EPS*), whereas the further overall rise in cost-effectiveness through regionalization leads to less equality and less equity.

Table 3 Comparison over Saxony and for each region of the cost-effectiveness measures ($Eff_{all}$ in Eq. 6), the equality measures (*EP* in Eq. 10) and equity measures (*EPS* in Eq. 11)

| Comparison based on: | spatial level | variable | simul | opti10 | regopti10 |
|---|---|---|---|---|---|
| Cost-effectiveness | Saxony | $Eff_{all}$ | 0.014 | 0.019 | **0.026** |
| | region 1 | $Eff_{all}1$ | 0.014 | 0.025 | **0.073** |
| | region 2 | $Eff_{all}2$ | 0.017 | **0.028** | 0.027 |
| | region 3 | $Eff_{all}3$ | 0.0131 | 0.0128 | **0.019** |
| Equality | Saxony | *EP* | 0.835 | 0.785 | 0.589 |
| | region 1 | *EP1* | 0.832 | 0.846 | 0.540 |
| | region 2 | *EP2* | 0.941 | 0.945 | 0.863 |
| | region 3 | *EP3* | 0.862 | 0.756 | 0.600 |
| Equity | Saxony | *EPS* | 0.527 | 0.800 | 0.522 |
| | region 1 | *EPS1* | 0.580 | 0.962 | 0.831 |
| | region 2 | *EPS2* | 0.573 | 0.994 | 0.979 |
| | region 3 | *EPS3* | 0.629 | 0.535 | 0.537 |

*Note: bold type indicates the most cost-effective scheme in each region and for Saxony; blue indicates that the optimizations are more equal/equitable than the simulation.*

Considering the situation within regions, the payments are more equally distributed in the Saxon AES than in the optimizations in region 3 with the largest grassland area. In the other two regions, the statewide optimization leads to a slightly more equal *P* distribution than the Saxon AES, because there are only low number of measures are applied. Thus, in regions 1 and 2 higher cost-effectiveness through spatially homogeneous payments does not compromise equality (we have a synergy). The regional optimization however leads to a trade-off – a rise in inequality (lower *EP*) in all three regions, due to the lower payment levels and higher variation in *P*.

The *PS*-distributions from the optimizations within regions 1 and 2 are more homogeneous than in the Saxon AES, but less homogeneous within region 3. This means, in regions 1 and 2 increasing the overall cost-effectiveness with the optimizations leads to a synergy - an increase in equity - as expected, because the *PS* levels vary less, due to the orientation on opportunity costs and also much lower number of measures applied in the optimizations in these regions. In region 3, the variation of PS is higher in the optimizations than in the Saxon AES, because in the Saxon AES almost 50% of the participating area is covered by one measure, whereas in the optimizations there is not one single dominating measure and also due to the higher variation in opportunity costs in this region.

## 5.2 Comparison based on Rawls' maximin principle

To account for Rawlsian preferences, we focus on region 1, the "poorest region" with the lowest mean income (Table 1), and compare the payments (i.e. $P_{min}$, $P_{mean}$ and $P_{sum}$) and the net benefits generated (i.e. $PS_{min}$, $PS_{mean}$ and $PS_{sum}$) of the Saxon AES and the optimizations. Surprisingly in region 1 all three net benefit values, as well as $P_{min}$ and $P_{sum}$ are highest in the statewide optimization, only $P_{mean}$ is highest in the Saxon AES (Table 4, which has relatively low benefit-cost ratio and thus less relevance in the statewide optimization.).

Table 4 Regional comparison of the minimum and average payments ($P_{min}$, $P_{mean}$ and $P_{sum}$) and producer surplus ($PS_{min}$, $PS_{mean}$ and $PS_{sum}$) from the simulation and optimizations (values in Euro).

| **Region** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **PS1min** | PS2min | PS3min | **PS1mean** | PS2mean | PS3mean | **PS1sum** | PS2sum | PS3sum |
| **Simul** | 8.22 | 8.22 | 8.22 | 119.87 | 62.93 | 194.46 | 1 258 621 | 1 498 020 | 4 467 608 |
| **opti10** | **100** | 100 | 1.53 | **123.63** | 123.68 | 135.52 | **2 202 230** | 3 081 842 | 2 906 146 |
| **regopti10** | 0.02 | 62.55 | 0.37 | 31.73 | 127.11 | 23.19 | 565 233 | 3 167 524 | 497 265 |
| **Variable** | **P1min** | P2min | P3min | **P1mean** | P2mean | P3mean | **P1sum** | P2sum | P3sum |
| **Simul** | 79 | 79 | 79 | **200.42** | 122.06 | 266.78 | 2 104 425 | 2 905 838 | 6 129 313 |
| **opti10** | **89** | 89 | 89 | 131.61 | 112.77 | 271.45 | **2 344 288** | 2 810 044 | 5 820 881 |
| **regopti10** | 15 | 89 | 15 | 44.95 | 124.99 | 156.04 | 827 988 | 2 891 950 | 5 985 013 |
| **mean income (GOS+pers. costs)*/ worker** | **31,300** | 38,293 | 32,231 | **31,300** | 38,293 | 32,231 | **31,300** | 38,293 | 32,231 |

Thus, considering Rawlsian preferences, in our case the statewide optimization is better than the Saxon AES and the regional optimization, as it leads to higher net benefits ($PS_{min}$, $PS_{mean}$

and $PS_{sum}$) in the "poorest" region 1. Due to the low opportunity costs there a larger portion of the budget is allocated to this region in the statewide optimization.

Considering region 3, which is also relatively poor compared to region 2, the Saxon AES is best on the maximin criterion, because almost 50% of the participating area in the Saxon AES in this region is covered by a mowing measure with high *P* and *PS*, which has relatively low benefit-cost ratio and thus less relevance in the statewide optimization.

## 6 Discussion and conclusion

Here we analyze cost-effectiveness gains through regionalization of agri-environment schemes and the distributional impact of the regionalization applying the equality principle, the equity principle and Rawls' maximin principle. We carry out our analysis by modifying an existing ecological-economic modelling procedure (Wätzold et al., 2016; Sturm et al., 2018) so that we are able to investigate regional cost-effectiveness gains and their distributional impact. We apply the modelling procedure to the case study of a grassland AES in Saxony. We compare a Saxon AES to optimized schemes with (1) spatially homogeneous payments and (2) regionally differentiated payments.

Regarding the effects of regionalization on cost-effectiveness, we find that regionalization helps in increasing the level of bird, butterfly and habitat type conservation on the federal state level through aligning the measures applied and the payments to the opportunity costs of each region. In regions 1 and 2 (with less grassland area available), however, the regional payments do not enhance the protection of butterflies and habitat types. The increase in conservation for these species is realized mainly in region 3 with the largest grassland area and in general more species occurrence. Thus through regionalization a kind of specialization is possible by focusing payments and measures to the areas where, e.g. due to more species occurrence as in the case of butterflies, a higher conservation result is possible.

By including more measures in the optimizations and not restricting the measures to the ones from the Saxon AES, we could have obtained higher conservation levels for butterflies and habitat types (Wätzold et al. 2016). However, a large number of measures is associated with high transaction costs. In general, improving the cost effectiveness through implementing more-tailored regionally differentiated payments instead of simplified homogeneous payments brings a trade-off with equality but also with transaction costs, as suggested by Armsworth et al. (2012) for AES and Wätzold et al. (2010) for conservation measures in Natura 2000 sites. In this study, we show that high cost-effectiveness improvements in AES are possible without incurring much higher transaction cost, by only choosing a limited number of measures for each region and setting regional payments. Whether in reality the transaction costs in implementing such a regionalized AES with fixed payments within regions are low, having in mind its distributional effects, is a matter of future research. Future research can also give more insights on the effects of spatial differentiation on cost-effectiveness and distributive fairness of AES in practice.

In our theoretical analysis of distributive impacts, we apply three fairness principles: equality, equity and Rawls' maximin criterion. If we choose equality as fairness principle, on the federal state level and in region 3 the Saxon AES is superior to the more cost-effective, optimized ones. If we look at fairness as equity, and choose accountability as the fairness principle, then the increase in cost-effectiveness in the optimized schemes leads in general to more equity, except in region 3 – the region with largest grassland area and relatively low opportunity costs.

The spatially homogeneous optimized payments perform best on the maximin criterion and also lead to highest equality and equity in regions 1 and 2. Therefore, in our case study we do not find strong trade-offs in cost-effectiveness and equality/equity between the Saxon AES and the optimization with spatially homogeneous payments, except in region 3, with the highest number of farms.

Compared to the statewide optimized scheme the regionalized payments lead to an overall rise in cost-effectiveness, but also to less equality and less equity. Especially prominent trade-off between cost-effectiveness and equality through regionalization is present in region 1, where with 60% less budget the regionally differentiated payments generate twice as much $A_{tot}^{eff}$ as the Saxon AES. By contrast, in the statewide optimization, where the budget constraint is set on the federal state level, almost the same improvement in conservation is achieved in region 1 with much higher budget (11 % higher than in the Saxon AES in region 1). Thus, in region 1, the "poorest" region, spatially homogeneous payments lead to more fairness based on the equality, equity and the maximin criterion, but are much less cost-effective than the regionalized payments.

Uthes et al. (2010) also suggest that effectiveness and cost-effectiveness are sacrificed with the usual design of AES with homogeneous payments and with the additional goal of rural income creation. They propose that in line with Tinbergen (1952) the two goals should be targeted with two instruments and a way to increase the efficiency and effectiveness of an AES could be to distribute "a basic payment to all livestock-keeping farms for their contribution to the rural environment, and an additional top-up payment for environmental services to farms that actually reduce livestock density and adjust grassland management." To account for Rawlsian preferences and keep direct payments low they could be limited to a certain amount and scaled according to the size of the farm (smallest, small, medium, large) and in combination with an income parameter (such as income (e.g. gross operating surplus+personnel costs) per worker. This could possibly be an alternative to the proposed "reduction of payments as of €60,000 and compulsory capping for payments above €100,000 per farm" (where labour costs are taken fully into account) in the CAP (Common Agricultural Policy) post 2020 (European Commision, 2018).

In our case study, homogeneous optimized payments are actually superior to regionally differentiated payments in region 2 – with the highest opportunity costs (i.e. "richest" region), where differentiated payments do not lead to more cost-effectiveness. There, as in region 1 (the "poorest" region), we have synergies between cost-effectiveness and equality, and equity resulting from homogeneous optimized payments. The more cost-effective regionalized payments lead to substantial redistribution effects and lower substantially the producer surplus for farmers in the "poorer" regions 1 and 3, but increase the producer surplus for farmers in the "richer" region 2. This trade-off between maximizing public policies' performance on a supra-regional (national) level and the corresponding regional performance and distributive fairness is also identified in Mouysset (2014) and highlights the importance of analyzing public policy effects on different levels – state, federal state, and regional levels.

Also important is a discussion on the socially desirable fairness principle in AES. Literature on PES offers more insights into this issue and suggests different fairness preferences of ecosystem service (ES) providers (e.g. farmers). Loft et al. (2017) find a preference for merit-system distribution, i.e. equity, among PES participants in Vietnam, whereas Gross-Camp et al. (2012) and Narloch et al. (2011) find preferences for an equal distribution in Rwanda and the Andes, respectively. In Markova-Nenova and Wätzold (2017) and Randrianarison and Waetzold (2017) potential ES buyers (donors) in Germany and in Madagascar show preferences for a maximin or equal distribution over an unknown distribution of PES in Madagascar. Based on a study on preferences for ethical milk attributes Markova-Nenova and Wätzold (2018) suggest that poor farmers' support is important for milk buyers as taxpayers and potential ES buyers and support for all farmers is approved of only in one's own region. A question arises how the fairness preferences would look like if ES buyers in AES had to choose between a less cost-effective, but fairer homogeneous payments scheme and a more cost-effective, but less fair regionalized scheme. This could be a topic for future research.

Unfortunately, we have only mean income data available for the three economic regions in Saxony, which makes the analysis based on the maximin principle difficult. Much more detailed research results on distribution could be possible, if farm data in Germany were available openly as in Sweden (Nordin and Höjgård, 2018). This would in general facilitate research on agricultural topics.

Another limitation of our analysis is the focus on three strictly defined social fairness principles relevant for the distribution of payments to farmers. We acknowledge that multiple dimensions of fairness exist, and pursuing different fairness objectives can lead to different results (Law et al., 2018). If we look at existence values (Schlosberg, 2009), or responsibility to future generations and to other species as environmental justice principles (Clayton, 2000) the fairness comparison will depend more strongly on the number of species conserved through an AES and the extent to which they are conserved.

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# Appendix A

## Tables:

Table A. 1 Measures according to Directive "Agricultural environmental measures and forestation" (Directive AuW/2007), part A, section G , "Extensive grassland use, nature conforming grassland management and conservation" (modified from Wätzold et al. 2016).

| **Name of measure and main requirements** [1] | **Payment per ha in €**[1] | **Size of area for this measure in 2013 in ha**[2] | **Overall expenses for this measure in 2013 in €**[2] |
|---|---|---|---|
| G1a (extensive grassland management pasture)[3] use of pasture or of pasture with early mowing, minimum (maximum) stocking rate of 0.3 (1.4) grazing livestock unit per ha (GLU/ha), maximum input of liquid manure not to exceed 1.4 LU/ha per annum, N fertilizer restriction according to EC 834/2007 | 108 | 23,734 | 2,563,272 |
| G1b (extensive grassland management meadow) extensive meadow, use of pasture allowed after 15 August (maximum stocking rate 1.4 GLU/ha), maximum input of liquid manure not to exceed 1.4 LU/ha per annum, N fertilizer restriction according to EC 834/2007 | 108 | 6,265 | 676,620 |
| G2 (conservation-enhancing meadow use; no fertiliser before mowing, 15 June) first mowing not allowed before 15 June (grazing only allowed after 1 August), no application of N fertilizer before first mowing | 312 | 3,092 | 964,704 |
| G3a (conservation-enhancing meadow use; general ban on fertiliser, 15 June) first mowing not allowed before 15 June (grazing only allowed after 1 August), complete ban on application of N fertilizer | 373 | 11,417 | 4,258,541 |
| G3b (conservation-enhancing meadow use; general ban on fertiliser, 15 July) first mowing not allowed before 15 July (grazing only allowed after 1 September), complete ban on application of N fertilizer | 394 | 3,105 | 1,223,370 |
| G5 (conservation-enhancing meadow use; ban on fertilizer, temporary halt of utilization)[4] minimum two mowings per year, completion of first mowing not after 10 June, second mowing not before 15 September, complete ban on application of N fertilizer | 392 | 805 | 315,560 |
| G6 (conservation-enhancing grazing, late beginning) minimum period of grazing each year with minimum stocking rate 0.3 GLU/ha, beginning of grazing not before 1 June, complete ban on application of N fertilizer | 190 | 4,701 | 893,190 |
| G9 (establishment of fallow land/strips on grassland) mowing and clearing of cut grass between 15 August and 15 November at least every two years, measure is only supported if (agriculturally used) grassland is adjacent, minimum size of 0.1 ha, maximum size of 2 ha, complete ban on application of N fertilizer | 536 | 368 | 197,248 |

**Note:** Overall budget spent on the above measures: 11,092,505 €

[1] Information and data from Saxon State Ministry of the Environment and Agriculture (2015)

[2] Data from Saxon State Ministry of the Environment and Agriculture (2014b, p.50)

[3] Since this measure prescribes either pasture or pasture with mowing, in the simulation it is divided into two land use measures.

[4] Since this measure prescribes two flexible time limits in the simulation it is divided into two land use measures with different mowing times.

Table A. 2 Ecological effectiveness of the Saxon grassland AES – results of the simulation, the optimization and the regional optimization

| Species or Habitat types | Simulation $A_j^{eff}$ in ha | Statewide optimization $A_j^{eff}$ in ha | Regional optimization $A_j^{eff}$ in ha |
|---|---|---|---|
| **Birds** | | | |
| Black Grouse | 12 139.77 | 13 847.09 | 18 208.59 |
| Corncrake | 4 618.03 | 20 117.37 | 18 709.76 |
| Crested Lark | 0.00 | 0.00 | 0.00 |
| Curlew | 7 014.24 | 3 417.95 | 7 067.10 |
| Garganey | 434.62 | 0.00 | 168.59 |
| Hoopoe | 762.49 | 17.79 | 1 398.82 |
| Lapwing | 11 618.22 | 20 401.44 | 23 449.90 |
| Meadow Pipit | 46 921.47 | 51 412.36 | 64 607.56 |
| Partridge | 16 715.04 | 24 138.54 | 28 057.03 |
| Redshank | 11 378.51 | 18 698.35 | 21 545.56 |
| Skylark | 8 615.30 | 16 816.79 | 19 395.99 |
| Snipe | 3 031.74 | 596.37 | 2 201.72 |
| Whinchat | 31 481.10 | 36 877.50 | 44 659.95 |
| **Butterflies** | | | |
| Amanda´s Blue | 0.00 | 0.00 | 0.00 |
| Chestnut Heath | 21.96 | 13.23 | 102.57 |
| Dingy Skipper | 0.00 | 0.00 | 0.00 |
| Dusky Large Blue | 0.00 | 25.39 | 7.04 |
| Five-spot Burnet | 7.30 | 0.00 | 33.35 |
| Glanville Fritillary | 0.00 | 0.00 | 0.00 |
| Large Wall Brown | 0.00 | 0.00 | 0.00 |
| Marsh Fritillary | 0.65 | 0.00 | 0.65 |
| Mazarine Blue | 0.00 | 0.00 | 0.00 |
| Purple-edged Copper | 2.36 | 0.00 | 88.71 |
| Scarce Large Blue | 0.00 | 0.00 | 0.00 |
| Silver-spotted Skipper | 0.00 | 0.00 | 0.00 |
| Small Blue | 0.00 | 0.00 | 0.00 |
| Woodland Ringlet | 13.31 | 0.00 | 88.06 |
| **Habitat types** | | | |
| Alluvial meadows | 612.50 | 867.55 | 428.29 |
| Lowland hay meadows | 1 840.14 | 822.41 | 0.00 |
| Molinia meadows | 0.00 | 0.00 | 0.00 |
| Mountain hay meadows | 836.35 | 3 157.33 | 3 362.31 |
| Nardus grassland | 0.00 | 0.00 | 0.00 |
| Semi-natural dry grassland | 0.00 | 0.00 | 0.00 |
| Wet meadows | 515.63 | 218.75 | 1 759.38 |
| **Total achieved effective area $A_{tot}^{eff}$ *** | **158 580.71** | **211 446.21** | **255 340.91** |
| ***% of all targeted species covered*** | **62%** | **50%** | **62%** |
| **Subtotal $A_{birds}^{eff}$** | **154 730.52** | **206 341.55** | **249 470.56** |
| ***% of targeted species covered*** | **92%** | **85%** | **92%** |
| **Subtotal$A_{butterflies}^{eff}$** | **45.58** | **38.62** | **320.37** |
| ***% of targeted species covered*** | **36%** | **14%** | **43%** |
| **Subtotal $A_{habitats}^{eff}$** | **3 804.61** | **5 066.04** | **5 549.98** |
| ***% of targeted species covered*** | **57%** | **57%** | **43%** |
| **Total participating area in ha** | **57 281.25** | **64 175.00** | **79 912.50** |

**Note:** * equals the sum of column values

Table A. 3 Results from the simulation, the statewide optimization and the regional optimization of the Saxon AES (10, 7 and 10 measures resp.)

| **Measure code*/ Measure ID** | **Run** | **Participating area per measure and region** | | | **Total part. area per measure in ha** | $A_{tot}^{eff}$ **per measure and region** | | | $A_{tot}^{eff}$ **per measure** | **Mean payment** $P_{mean}$ | | | **Mean producer surplus** $PS_{mean}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | region 1 | region 2 | region 3 | | region 1 | region 2 | region 3 | | region 1 | region 2 | region 3 | region 1 | region 2 | region 3 |
| Mowing 23/6/01, LU 0/ 96 | simul | 812.50 | 1 043.75 | 1 225.00 | 3 081.25 | 3 832.16 | 5 168.89 | 7 275.90 | 16 276.96 | 312 | 312 | 312 | 250.04 | 250.07 | 256.97 |
| | opti10 | - | - | 437.50 | 437.50 | - | - | 2 556.18 | 2 556.18 | - | - | 535 | - | - | 262.13 |
| | regopti10 | - | - | 3 556.25 | 3 556.25 | - | - | 21 363.45 | 21 363.45 | - | - | 304 | - | - | 27.09 |
| **Mowing 19/16/00,** LU **2/ 3410** | simul | 293.75 | 12.50 | 75.00 | 381.25 | 883.66 | 39.17 | 245.91 | 1 168.74 | 392 | 392 | 392 | 192.76 | 192.76 | 192.76 |
| | regopti10 | - | **293.75** | **237.50** | 531.25 | - | 892.23 | 778.91 | 1 671.15 | - | 631 | 372 | - | 275.99 | 59.02 |
| Mowing 21/14/00, LU 2/ 3413 | simul | 262.50 | 6.25 | 131.25 | 400.00 | 1 016.21 | 25.96 | 553.95 | 1 596.12 | 392 | 392 | 392 | 191.83 | 192.22 | 190.98 |
| | opti10 | 818.75 | - | 3 793.75 | 4 612.50 | 3 308.47 | - | 15 196.11 | 18 504.59 | 631 | - | 631 | 321.71 | - | 338.26 |
| | regopti10 | - | - | 687.50 | 687.50 | - | - | 2 735.04 | 2 735.04 | - | - | 351 | - | - | 10.33 |
| **Mowing 19/6/60,** LU **2/ 3439** | simul | 2 031.25 | 2 993.75 | 1 231.25 | 6 256.25 | 2 682.17 | 4 136.33 | 1 637.61 | 8 456.10 | 108 | 108 | 108 | 51.19 | 51.63 | 51.40 |
| | regopti10 | - | - | **1 806.25** | 1 806.25 | - | - | 2 379.58 | 2 379.58 | - | - | 401 | - | - | 40.47 |
| Mowing 23/6/60, LU 2/ 3503 | simul | - | 6.25 | 11 193.75 | 11 200.00 | - | 30.11 | 51 977.79 | 52 007.90 | - | 373 | 373 | - | 299.59 | 302.63 |
| | opti10 | - | - | 4 281.25 | 4 281.25 | - | - | 20 025.59 | 20 025.59 | - | - | 374 | - | - | 5.09 |
| | regopti10 | - | 18.75 | 2 675.00 | 2 693.75 | - | 93.85 | 12 185.47 | 12 279.32 | - | 465 | 405 | - | 68.16 | 50.91 |
| **Mowing 27/6/60,** LU **2/ 3550** | simul | 2 118.75 | 31.25 | 931.25 | 3 081.25 | 13 475.48 | 186.24 | 6 058.41 | 19 720.13 | 394 | 394 | 394 | 290.53 | 285.76 | 288.56 |
| | regopti10 | **756.25** | **506.25** | **2 406.25** | 3 668.75 | 5 071.95 | 3 175.68 | 17 426.56 | 25 674.19 | 432 | 747 | 449 | 39.66 | 315.98 | 74.04 |
| Rotational grazing 19/6/62, LU 101/ 3610 | simul | 1 900.00 | 2 093.75 | 3 500.00 | 7 493.75 | 2 779.26 | 2 844.47 | 4 656.19 | 10 279.92 | 108 | 108 | 108 | 38.67 | 45.03 | 37.95 |
| | opti10 | 2 425.00 | 4 818.75 | 4 293.75 | 11 537.50 | 3 442.06 | 6 636.02 | 5 742.71 | 15 820.79 | 157 | 157 | 157 | 112.64 | 123.78 | 111.58 |
| | regopti10 | 1 768.75 | 3 875.00 | 2 381.25 | 8 025.00 | 2 620.77 | 5 408.92 | 3 182.31 | 11 212.00 | 49 | 157 | 49 | 11.19 | 128.37 | 9.37 |
| Rotational grazing 21/6/62, LU 101/ 3642 | simul | 625.00 | 2 668.75 | 1 393.75 | 4 687.50 | 1 081.32 | 4 972.74 | 3 149.31 | 9 203.37 | 190 | 190 | 190 | 137.51 | 137.18 | 138.38 |
| | opti10 | 193.75 | - | 1 081.25 | 1 275.00 | 390.88 | - | 2 850.97 | 3 241.85 | 163 | - | 163 | 127.28 | - | 129.91 |
| | regopti10 | - | 943.75 | 7 768.75 | 8 712.50 | - | 1 707.77 | 20 332.10 | 22 039.87 | - | 163 | 52 | - | 105.21 | 7.81 |
| Mowing & pasture comb. 19/6/62, LU 101/ 3739 | simul | 2 093.75 | 11 056.25 | 3 037.50 | 16 187.50 | 2 977.07 | 15 652.11 | 3 979.75 | 22 608.93 | 108 | 108 | 108 | 13.48 | 12.58 | 12.88 |
| | opti10 | 925.00 | 1 800.00 | 468.75 | 3 193.75 | 1 353.82 | 2 419.56 | 617.54 | 4 390.92 | 236 | 236 | 236 | 164.97 | 164.97 | 164.97 |
| | regopti10 | 2 381.25 | - | 11 556.25 | 13 937.50 | 3 362.63 | - | 15 456.42 | 18 819.05 | 89 | - | 94 | 13.86 | - | 8.22 |
| Mowing strips 19/6/6 1, LU 2/ 3922 | simul | 362.50 | 3 893.75 | 256.25 | 4 512.50 | 1 253.58 | 15 048.51 | 960.45 | 17 262.53 | 79 | 79 | 79 | 113.93 | 120.34 | 112.84 |
| | opti10 | 13 450.00 | 18 300.00 | 7 087.50 | 38 837.50 | 49 343.61 | 69 866.59 | 27 696.09 | 146 906.29 | 89 | 89 | 89 | 110.66 | 119.59 | 111.39 |
| | regopti10 | 13 512.50 | 17 500.00 | 5 281.25 | 36 293.75 | 49 590.21 | 66 970.23 | 20 606.82 | 137 167.27 | 15 | 89 | 15 | 37.13 | 120.12 | 39.12 |
| **Totals per region** | **simul** | **10 500.00** | **23 806.25** | **22 975.00** | **57 281.25** | **29 980.91** | **48 104.52** | **80 495.28** | **158 580.71** | **200.42** | **122.06** | **266.78** | **119.87** | **62.93** | **194.46** |
| | **opti10** | **17 812.50** | **24 918.75** | **21 443.75** | **64 175.00** | **57 838.86** | **78 922.16** | **74 685.19** | **211 446.21** | **131.61** | **112.77** | **271.45** | **123.63** | **123.68** | **135.52** |
| | **regopti10** | **18 418.75** | **23 137.50** | **38 356.25** | **79 912.50** | **60 645.57** | **78 248.69** | **116 446.65** | **255 340.91** | **44.95** | **124.99** | **156.04** | **31.73** | **127.11** | **23.19** |

Table A. 3 continued

| **Measure code*/ Measure ID** | **Run** | **Budget per measure and region** | | | **Total budget per measure** | **PS per measure and region** | | | **Total PS per measure** |
|---|---|---|---|---|---|---|---|---|---|
| | | region 1 | region 2 | region 3 | | region 1 | region 2 | region 3 | |
| Mowing 23/6/01, LU 0/ 96 | simul | 253 500.00 | 325 650.00 | 382 200.00 | 961 350.00 | 203 159.59 | 261 015.21 | 314 791.32 | 778 966.11 |
| | opti10 | - | - | 234 062.50 | 234 062.50 | - | - | 114 682.88 | 114 682.88 |
| | regopti10 | - | - | 1 081 100.00 | 1 081 100.00 | - | - | 96 334.16 | 96 334.16 |
| **Mowing 19/16/00,** LU **2/ 3410** | simul | 115 150.00 | 4 900.00 | 29 400.00 | 149 450.00 | 56 621.78 | 2 409.44 | 14 456.63 | 73 487.84 |
| | regopti10 | - | 185 356.25 | 88 350.00 | 273 706.25 | 0.00 | 81 073.24 | 14 016.86 | 95 090.10 |
| Mowing 21/14/00, LU 2/ 3413 | simul | 102 900.00 | 2 450.00 | 51 450.00 | 156 800.00 | 50 356.34 | 1 201.38 | 25 066.63 | 76 624.34 |
| | opti10 | 516 631.25 | - | 2 393 856.25 | 2 910 487.50 | 263 403.29 | - | 1 283 280.09 | 1 546 683.38 |
| | regopti10 | - | - | 241 312.50 | 241 312.50 | - | - | 7 104.18 | 7 104.18 |
| **Mowing 19/6/60,** LU **2/ 3439** | simul | 219 375.00 | 323 325.00 | 132 975.00 | 675 675.00 | 103 981.54 | 154 558.61 | 63 288.97 | 321 829.12 |
| | regopti10 | - | - | 724 306.25 | 724 306.25 | - | - | 73 094.81 | 73 094.81 |
| Mowing 23/6/60, LU 2/ 3503 | simul | - | 2 331.25 | 4 175 268.75 | 4 177 600.00 | - | 1 872.41 | 3 387 538.15 | 3 389 410.56 |
| | opti10 | - | - | 1 601 187.50 | 1 601 187.50 | - | - | 21 803.01 | 21 803.01 |
| | regopti10 | - | 8 718.75 | 1 083 375.00 | 1 092 093.75 | - | 1 278.01 | 136 186.94 | 137 464.95 |
| **Mowing 27/6/60,** LU **2/ 3550** | simul | 834 787.50 | 12 312.50 | 366 912.50 | 1 214 012.50 | 615 565.59 | 8 930.09 | 268 720.01 | 893 215.69 |
| | regopti10 | 326 700.00 | 378 168.75 | 1 080 406.25 | 1 785 275.00 | 29 993.50 | 159 964.64 | 178 166.52 | 368 124.66 |
| Rotational grazing 19/6/62, LU 101/ 3610 | simul | 205 200.00 | 226 125.00 | 378 000.00 | 809 325.00 | 73 468.33 | 94 272.02 | 132 835.66 | 300 576.01 |
| | opti10 | 380 725.00 | 756 543.75 | 674 118.75 | 1 811 387.50 | 273 153.36 | 596 477.44 | 479 108.94 | 1 348 739.74 |
| | regopti10 | 86 668.75 | 608 375.00 | 116 681.25 | 811 725.00 | 19 785.74 | 497 452.70 | 22 318.38 | 539 556.82 |
| Rotational grazing 21/6/62, LU 101/ 3642 | simul | 118 750.00 | 507 062.50 | 264 812.50 | 890 625.00 | 85 946.69 | 366 101.92 | 192 868.73 | 644 917.34 |
| | opti10 | 31 581.25 | - | 176 243.75 | 207 825.00 | 24 659.92 | - | 140 468.39 | 165 128.31 |
| | regopti10 | - | 153 831.25 | 403 975.00 | 557 806.25 | - | 99 295.31 | 60 689.44 | 159 984.75 |
| Mowing & pasture comb. 19/6/62, LU 101/ 3739 | simul | 226 125.00 | 1 194 075.00 | 328 050.00 | 1 748 250.00 | 28 220.72 | 139 086.42 | 39 127.08 | 206 434.22 |
| | opti10 | 218 300.00 | 424 800.00 | 110 625.00 | 753 725.00 | 152 595.40 | 296 942.40 | 77 328.75 | 526 866.55 |
| | regopti10 | 211 931.25 | - | 1 086 287.50 | 1 298 218.75 | 33 008.66 | - | 94 953.55 | 127 962.21 |
| Mowing strips 19/6/6 1, LU 2/ 3922 | simul | 28 637.50 | 307 606.25 | 20 243.75 | 356 487.50 | 41 300.47 | 468 572.49 | 28 914.98 | 538 787.94 |
| | opti10 | 1 197 050.00 | 1 628 700.00 | 630 787.50 | 3 456 537.50 | 1 488 418.39 | 2 188 422.57 | 789 474.17 | 4 466 315.14 |
| | regopti10 | 202 687.50 | 1 557 500.00 | 79 218.75 | 1 839 406.25 | 501 682.38 | 2 102 037.99 | 206 589.18 | 2 810 309.55 |
| **Totals per region** | **simul** | **2 104 425.00** | **2 905 837.50** | **6 129 312.50** | **11 139 575.00** | **1 258 621.06** | **1 498 019.99** | **4 467 608.14** | **7 224 249.19** |
| | **opti10** | **2 344 287.50** | **2 810 043.75** | **5 820 881.25** | **10 975 212.50** | **2 202 230.36** | **3 081 842.42** | **2 906 146.22** | **8 190 219.00** |
| | **regopti10** | **827 987.50** | **2 891 950.00** | **5 985 012.50** | **9 704 950.00** | **584 470.26** | **2 941 101.89** | **889 454.03** | **4 415 026.19** |

Note: *The first number in the code is the quarter month (QM) of the first cut/beginning of grazing, the second (third) number indicates the interval between the first (second) cut and second (third) cut in QM. The forth number indicates that N-fertilizer is not allowed: 0 (only after the first cut: 1), while LU indicates the maximum grazing livestock unit permitted. For example, "mowing 19/6/60 LU 2" means that the first cut is not allowed before the 19QM, a second cut is allowed six weeks later, a third cut or grazing is allowed six weeks after the second cut, and the use of N fertilizer is not allowed, the maximum grazing livestock units shall not exceed 2 LU (corresponds to measure G1b in Table A. 1).

Table A. 4 Comparison over Saxony and for each region of the cost-effectiveness measures ($Eff_{type}$ in Eq. 6)

| **spatial level** | **variable** | **simul** | **opti10** | **regopti10** |
|---|---|---|---|---|
| Saxony | $Eff_{Birds}$ | 0.014 | 0.019 | **0.026** |
| region 1 | $Eff_{Birds}1$ | 0.014 | 0.024 | **0.073** |
| region 2 | $Eff_{Birds}2$ | 0.016 | **0.028** | 0.027 |
| region 3 | $Eff_{Birds}3$ | 0.013 | 0.012 | **0.019** |
| Saxony | $Eff_{Butterflies}$ | 0.0000041 | 0.0000035 | **0.0000330** |
| region 1 | $Eff_{Butterflies}1$ | 0.0000003 | 0.0000000 | **0.0000008** |
| region 2 | $Eff_{Butterflies}2$ | **0.0000053** | 0.0000047 | 0.0000000 |
| region 3 | $Eff_{Butterflies}3$ | 0.0000048 | 0.0000044 | **0.0000534** |
| Saxony | $Eff_{Habitats}$ | 0.00034 | 0.00046 | **0.00057** |
| region 1 | $Eff_{Habitats}1$ | **0.00058** | 0.00055 | 0.00000 |
| region 2 | $Eff_{Habitats}2$ | **0.00028** | 0.00000 | 0.00008 |
| region 3 | $Eff_{Habitats}3$ | 0.00029 | 0.00065 | **0.00089** |

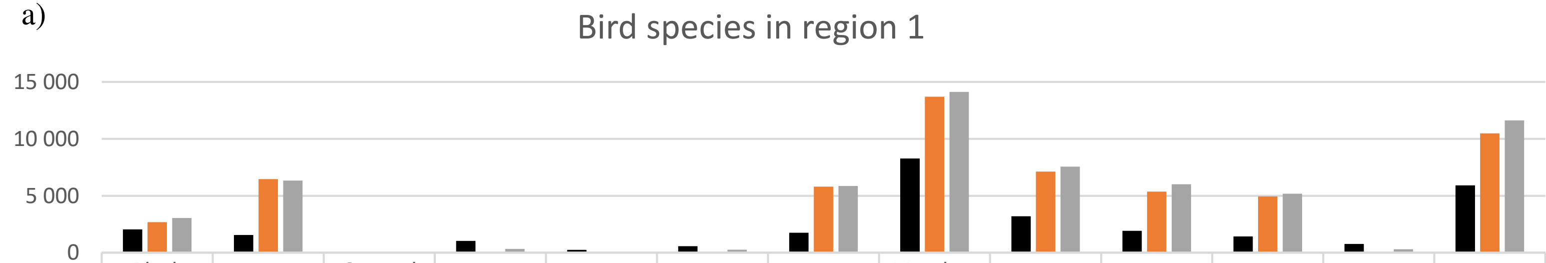
*Note: red indicates that optimizations are less cost-effective than the simulation;*

*bold type indicates the most cost-effective scheme on each indicator in each region and*

*bold green indicates the most cost-effective scheme on each indicator on federal state level for Saxony.*

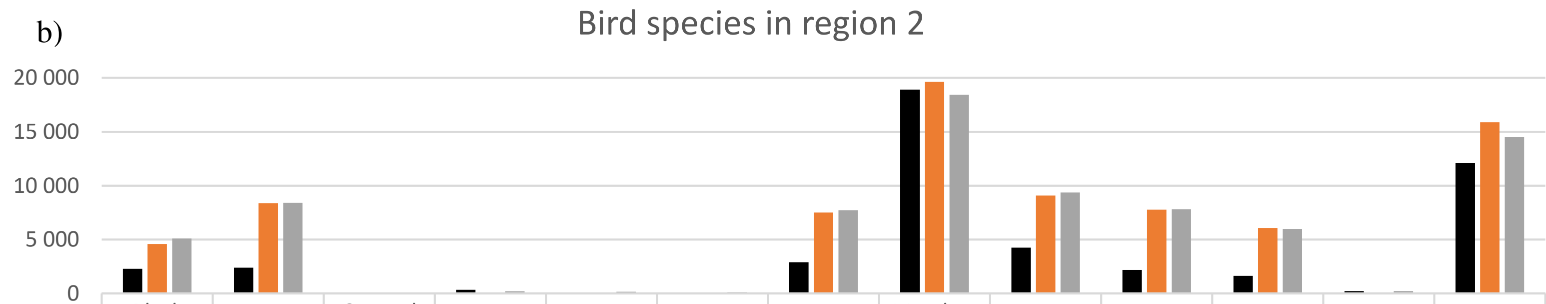
## Figures:

a)




| | Black Grouse | Corncrake | Crested Lark | Curlew | Garganey | Hoopoe | Lapwing | Meadow Pipit | Partridge | Redshank | Skylark | Snipe | Whinchat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| simul | 2 050 | 1 562 | 0 | 1 033 | 254 | 581 | 1 757 | 8 273 | 3 199 | 1 923 | 1 430 | 777 | 5 917 |
| opti10 | 2 677 | 6 457 | 0 | 8 | 0 | 0 | 5 797 | 13 696 | 7 116 | 5 366 | 4 950 | 0 | 10 476 |
| regopti10 | 3 044 | 6 342 | 0 | 337 | 10 | 270 | 5 853 | 14 122 | 7 551 | 6 009 | 5 183 | 312 | 11 612 |

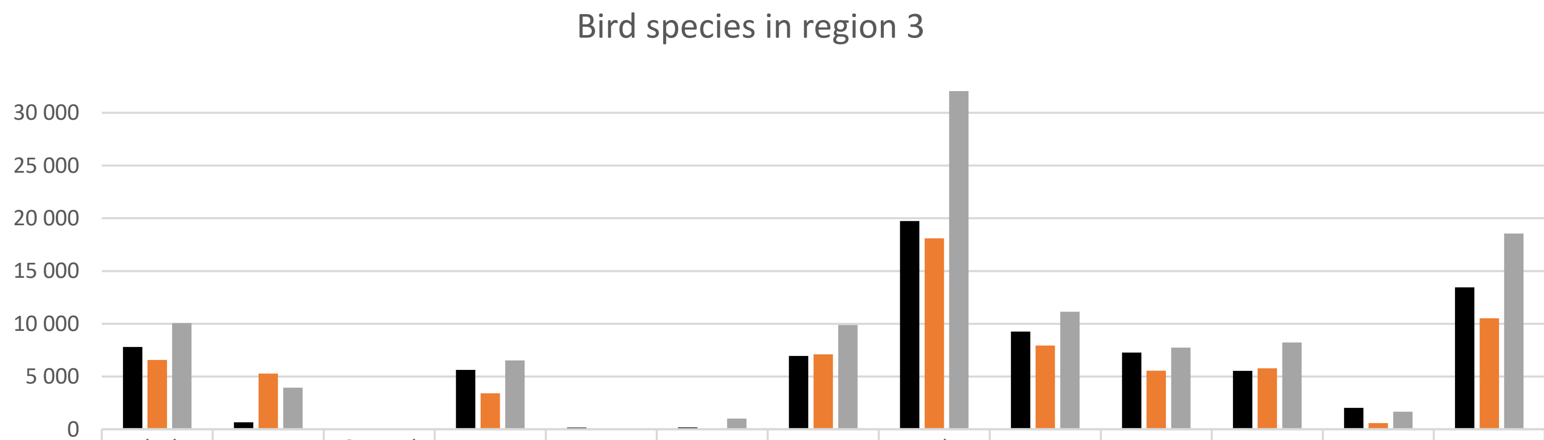
b)




| | Black Grouse | Corncrake | Crested Lark | Curlew | Garganey | Hoopoe | Lapwing | Meadow Pipit | Partridge | Redshank | Skylark | Snipe | Whinchat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| simul | 2 288 | 2 396 | 0 | 343 | 11 | 4 | 2 905 | 18 909 | 4 253 | 2 189 | 1 638 | 228 | 12 109 |
| opti10 | 4 590 | 8 374 | 0 | 0 | 0 | 0 | 7 505 | 19 618 | 9 088 | 7 778 | 6 079 | 0 | 15 877 |
| regopti10 | 5 100 | 8 414 | 0 | 209 | 159 | 114 | 7 721 | 18 436 | 9 366 | 7 799 | 5 987 | 219 | 14 501 |

Figure A. 1 Regional comparison of the ecological effectiveness of the simulation (simul), the statewide optimization (opti10) and regional optimization (regopti10) for birds in region 1 (a), region 2 (b) and region 3 (c). The y-axis indicates the effective habitat area $A_j^{eff}$ in ha achieved for each species.

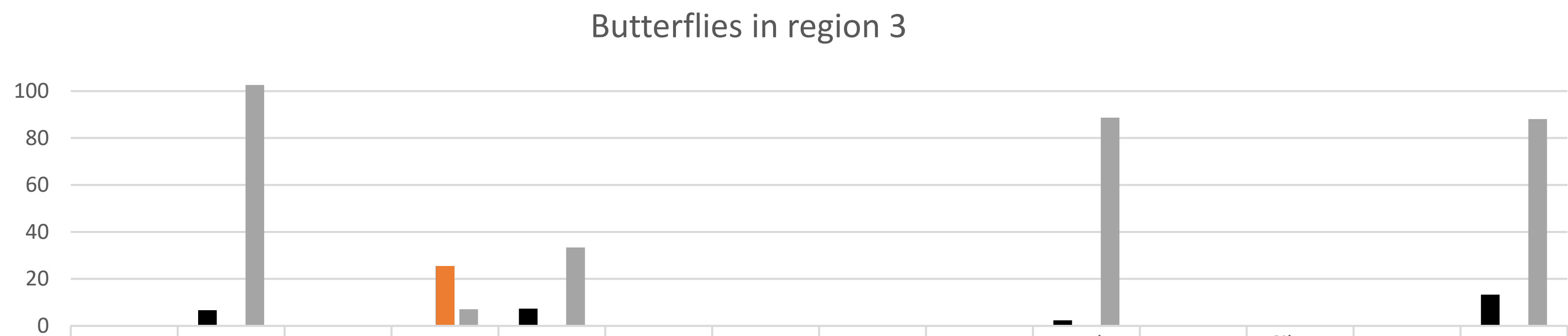
c)




| | Black Grouse | Corncrake | Crested Lark | Curlew | Garganey | Hoopoe | Lapwing | Meadow Pipit | Partridge | Redshank | Skylark | Snipe | Whinchat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| simul | 7 801 | 660 | 0 | 5 638 | 170 | 178 | 6 957 | 19 740 | 9 263 | 7 266 | 5 547 | 2 027 | 13 455 |
| opti10 | 6 580 | 5 286 | 0 | 3 410 | 0 | 18 | 7 100 | 18 098 | 7 934 | 5 554 | 5 788 | 596 | 10 525 |
| regopti10 | 10 065 | 3 954 | 0 | 6 520 | 0 | 1 015 | 9 876 | 32 050 | 11 140 | 7 738 | 8 225 | 1 671 | 18 547 |

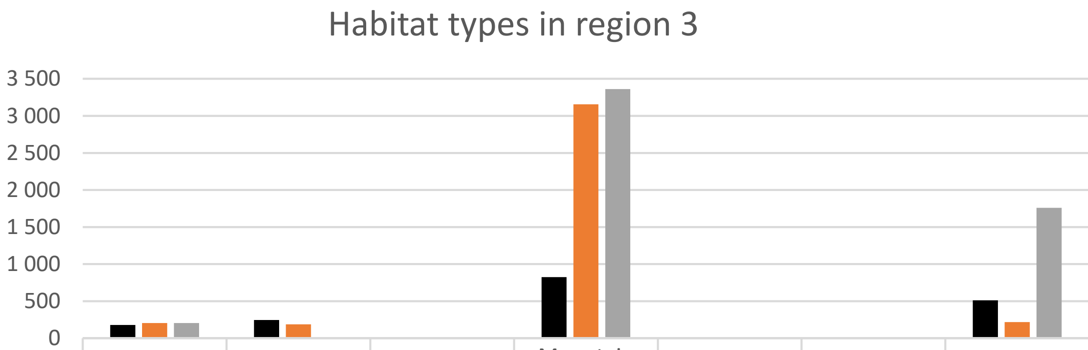
Figure A. 3 (continued)

Regional comparison of the ecological effectiveness of the simulation (simul), the statewide optimization (opti10) and regional optimization (regopti10) for birds in region 3 (c). The y-axis indicates the effective habitat area $A_j^{eff}$ in ha achieved for each species




| | Amanda´s Blue | Chestnut Heath | Dingy Skipper | Dusky Large Blue | Five-spot Burnet | Glanville Fritillary | Large Wall Brown | Marsh Fritillary | Mazarine Blue | Purple-edged Copper | Scarce Large Blue | Silver-spotted Skipper | Small Blue | Woodland Ringlet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **region 3** | | | | | | | | | | | | | | |
| ■ simul | 0 | 6,69 | 0 | 0 | 7,30 | 0 | 0 | 0 | 0 | 2,36 | 0 | 0 | 0 | 13,31 |
| ■ opti10 | 0 | 0 | 0 | 25,39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ■ regopti10 | 0 | 102,57 | 0 | 7,04 | 33,35 | 0 | 0 | 0 | 0 | 88,71 | 0 | 0 | 0 | 88,06 |
| **region 1** | | | | | | | | | | | | | | |
| ■ simul | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.65 | 0 | 0 | 0 | 0 | 0 | 0 |
| ■ opti10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ■ regopti10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.65 | 0 | 0 | 0 | 0 | 0 | 0 |
| **region 2** | | | | | | | | | | | | | | |
| ■ simul | 0 | 15.27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ■ opti10 | 0 | 13.23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ■ regopti10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure A. 2 Regional comparison of the ecological effectiveness of the simulation (simul), the statewide optimization (opti10) and regional optimization (regopti10) for butterflies in region 1, 2 and 3. The y-axis indicates the effective habitat area $A_j^{eff}$ in ha achieved for each species.




| region 3 | Alluvial meadows | Lowland hay meadows | Molinia meadows | Mountain hay meadows | Nardus grassland | Semi-natural dry grassland | Wet meadows |
|---|---|---|---|---|---|---|---|
| simul | 179 | 247 | 0 | 825 | 0 | 0 | 513 |
| opti10 | 206 | 188 | 0 | 3 157 | 0 | 0 | 219 |
| regopti10 | 206 | 0 | 0 | 3 362 | 0 | 0 | 1 759 |
| **region 1** | | | | | | | |
| simul | 422 | 803 | 0 | 0 | 0 | 0 | 0 |
| opti10 | 662 | 635 | 0 | 0 | 0 | 0 | 0 |
| regopti10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **region 2** | | | | | | | |
| simul | 12 | 791 | 0 | 11 | 0 | 0 | 3 |
| opti10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| regopti10 | 223 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure A. 3 Regional comparison of the ecological effectiveness of the simulation (simul), the statewide optimization (opti10) and regional optimization (regopti10) for habitat types in region 1, 2 and 3. The y-axis indicates the effective habitat area $A_j^{eff}$ in ha achieved for each species.

## Appendix B

For our analysis we consider farms with a relatively high percentage of grassland area which are likely to participate in a grassland AES (e.g. cattle and dairy farms). In Saxony these are the following types of farms with a relatively high percentage of grassland area which are likely to participate in a grassland AES according to TF8 grouping of the FADN (Farm Accountancy Data Network) with the respective EU-code (European Commission, 2019):

- 450. Specialist dairying
- 460. Specialist cattle - rearing and fattening
- 470. Cattle - dairying, rearing and fattening combined
- 482. Sheep and cattle combined
- 483. Specialist goats
- 484. Various grazing livestock
- 731. Mixed livestock, mainly dairying
- 831. Field crops combined with dairying
- 832. Dairying combined with field crops