Title:

Cost-effectiveness, Distributional Impacts and Regionalization in Agri-Environment Scheme Design. 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 between improving the cost-effectiveness of an AES and its distributional impacts exist. We further contribute to the analysis of spatially differentiated AES by assessing the gains in cost-effectiveness through a regionally differentiated AES optimization. Using an ecological-economic modelling procedure, we simulate a Saxon AES and design two more cost-effective AES - one scheme with homogeneous payments and one regionally differentiated payment scheme. To compare the distributional impacts of the schemes we use the criteria of equality, equity and Rawls' maximin criterion. Our results suggest a trade-off between equality and cost-effectiveness, whereas equity increases with improved cost-effectiveness of the AES. Regional optimization of payments results in less inequality, but also less equity than homogeneous optimized payments. Regionalization also leads to higher cost-effectiveness in bird conservation, but is actually worse for butterflies and habitat type conservation than an overall cost-effective AES.

Keywords: cost-effectiveness, distribution, fairness, 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 PSA program in Costa Rica or the Sloping Land Conversion Program in China (Wunder et al., 2008)) where they are usually referred to using the more general economic term Payments for Environmental Services (PES).

A large part of economic analysis of AES has focused on how to improve their cost-effectiveness, here understood as how to design AES so that for the available financial resources environmental, biodiversity and landscape aims are achieved to the greatest possible extent (e.g. Engel et al., 2008; see Ansell et al., 2016 for a review).

Especially in the research on biodiversity conservation, regarding the design of cost-effective AES the spatial optimization of schemes has become a key concern (Engel, 2015; Hanley et al., 2012). Four threads of discussion can be distinguished: 1) The first thread analyzes possible improvement in cost-effectiveness through spatial targeting of payments, i.e. “applying conservation measures on the most vulnerable or suitable land parcels” whereby “environmental effects are provided at lower costs than if conducted elsewhere” (Uthes et al., 2010a). 2) The second thread investigates incentives to provide spatially aggregated (Parkhurst et al., 2002) or non-aggregated and evenly allocated conservation areas (Bamière et al., 2011). A focus has been on analyzing the cost-effectiveness of payment designs such as agglomeration bonus and agglomeration payment schemes to provide spatially aggregated habitats (Drechsler et al., 2016; Lewis et al., 2011; Wätzold and Drechsler, 2014). 3) 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). Landscape-scale conservation management is considered relatively more efficient than farm-scale management in the case of mobile species, which require a spatial habitat pattern on larger scale (Cong et al., 2014). 4) The forth thread has received somewhat less attention and 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 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 (exceptions include Claassen et al., 2001, and Wu and Yu, 2017), whereas equity considerations have been discussed more often in the field of conservation (Friedman et al., 2018) and of PES in particular in relation to development issues (e.g. Markova-Nenova and Wätzold, 2017; McDermott, Mahanty and Schreckenberg, 2013; Pascual et al., 2010). One reason may be that distributional equity involves more normative judgement and varying definitions and measurement criteria. However, distributional impacts of policies are of high concern to policy makers and the public, and the implementation of cost-effective policies tends to receive much more support, if their distributional impacts are desirable. Synergies and trade-offs of efficiency / cost-effectiveness and equity have been analyzed in some environmental policy fields such as land conservation (Ay and Napoléone, 2013) and forest policies (Alix-Garcia, Janvry, and Sadoulet, 2004; Riera et al., 2007). Vorlaufer et al. (2017) discuss efficiency (environmental additionality) equity trade-offs in PES based on a framed field experiment among Indonesian rubber agro-forestry farmers.

With respect to AES efficiency equity trade-offs are studied by Wu and Yu (2017) using the CRP as a case study. They assess equity-in-outcome and equity-in-access (see Brown and Corbera, 2003) using different indicators and also show the payment distribution among low-income counties. They find that the analyzed CRP is quite efficient, but not very equitable on most indicators used, even though large part of the fund goes to lower-income counties. They also show that it is possible to increase both the efficiency and equity of the CRP by redistributing payments, i.e. by reducing CRP involved land "in counties with the highest rental rates" and "in counties with the highest CRP concentrations". Claassen et al. (2001) also identify and analyze some trade-offs in the design of AES. Using hypothetical scenarios for the implementation of a policy with the environmental goal of reducing water quality damage due to sediments, they investigate who gains and who loses from the policy and the spatial distribution of gains and losses. They conclude that payments based on improved performance compared to a baseline are more cost-effective and lead to largest improvement in farm income per dollar of payment compared to payments based on good performance or good practices. However, reaching two goals (e.g. environmental improvement and farm income improvement) with one policy is hardly possible. The latter is also proposed by Uthes et al. (2010b) who suggest that having rural development as a goal undermines achieving environmental benefits and cost-effectiveness of AES.

In this paper, we combine research on improving the cost-effectiveness of AES with analyzing the distributional impact of the proposed cost-effective alternative AES. We investigate for a case study (the grassland AES in the federal state of Saxony, Germany in 2013 - in the following Saxon AES), if there are trade-offs or synergies between improving the cost-effectiveness of AES and the resulting distributional impacts. Similar to Armsworth et al. (2012), we empirically investigate the cost-effectiveness gains of spatially differentiated payments over spatially homogeneous payments. We go beyond other cost-effectiveness analyses by explicitly considering the distributional impacts of the cost-effectiveness improvements to identify trade-offs and synergies.

We use the ecological-economic modelling procedure from Wätzold et al. (2016) to simulate the Saxon grassland AES, and to design two cost-effective alternatives, one scheme with homogeneous payments for the whole of Saxony and one with payments and measures differentiated according to the three Saxon agri-economic regions. We then compare the distributional impacts of the simulated Saxon AES with the more cost-effective alternatives. For the evaluation of the distributional impacts, we use the criteria of equality and equity/accountability (Ohl et al., 2008) and Rawls' (1971) 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, each of which covers areas with similar physio-geographic characteristics as preconditions for agricultural production.

As depicted in Figure A. 1, from north to south the three agri-economic regions are Saxon Heath and Pond Landscape (Sächsisches Heide- und Teichlandschaft), Saxon Loess Region (Sächsisches Lößgebiet) and 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, to the south and east, the altitude continually rises to an average of 900 m. Altitude is the main factor influencing the differences in climatic conditions in the different regions and it also influences the vegetation types (Saxon State Institute for

Agriculture, 1999). The slope gradient is another important factor for agricultural production, since it influences the use of agricultural machinery, the types of crops and the irrigation practices (Saxon State Institute for Agriculture, 1999). The soil productivity (expressed as grassland number) is on average best in region 2 (Table 1). Region 1, the lowland, covers a much smaller total agricultural area than the other two regions – three times smaller than region 2 and about 75% smaller than the agricultural area in region 3 (Statistical Office Saxony, 2010).

For our analysis we consider farms that usually take part in grassland AES, i.e. farms with a relatively high percentage of grassland area. In Saxony these are the following types of farms 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

Based on regional data from the Saxon State Ministry of the Environment and Agriculture (2014a), we find altogether 33 such farms in region 1, 131 farms in region 2 and 197 farms in region 3. As with the total agricultural area, the agricultural area covered by these farms in region 1 is smallest, three times smaller than in region 2 and region 3 (Table 1).

Table 1 Comparison of the analyzed grassland farms in the three agri-economic regions of Saxony. Source: Saxon State Ministry of the Environment and Agriculture (2014a and 2014c), own calculations.

Region	**Region 1**	**Region 2**	**Region 3**
Number of farms	33	131	197
Average grassland number	38	48	35
Range grassland number[#]	17-56	32-71	13-62
Agricultural land in ha	40,453	124,622	124,869

Region	Region 1	Region 2	Region 3
Agricultural land as percent of region 1	100.00%	308.07%	308.68%
Mean operating income in €/ farm	1,133,015	1,127,670	576,590
Mean operating income in €/ farm as percent of region 1	100.00%	99.53%	50.89%
Mean operating income in €/ ha	812	1,149	910
Mean operating income in €/ ha as percent of region 1	100.00%	141.50%	112.07%
EBT+ personnel expenses in €/ worker	31,464	38,139	32,693
EBT+ personnel expenses in €/ worker as percent of region 1	100.00%	121.21%	103.91%

Regional statistics on the above listed categories of farms are given in Table 1. When we look at mean operating income per average farm, the values for region 1 and 2 are similar, but the value for region 3 is about half the income per farm in the other two regions. This is due to the differences in size structure of farms among the regions. In region 1 there are few, comparatively large farms, whereas in region 3 there are many small farms. The most important income indicator, which is not directly dependent on the number and size of farms in the region and is used in official statistics to differentiate between different legal forms of farms, are the earnings before taxes plus personnel expenses per worker. On this factor, the income of region 2 is 20% higher than the income in region 1 and the income in region 3 is only slightly higher than in region 1 (4%). The mean operating income per hectare in region 2 is even 42% higher than that in region 1, which results from the high soil productivity in region 2. On this factor the income in region 3 is 12% higher compared to region 1. In sum, the income indicators are highest for region 2, due to the higher soil productivity there. The income indicators for region 3 are somewhat higher than those for 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 ignore the latter four measures, since they cannot be analyzed by the ecological-economic modelling procedure we apply, and consider only the eight mowing and grazing measures. Table A. 1 provides an overview of the measures we address, with the respective payments per hectare, size of participating area and overall payments per measure in 2013. The payments per hectare, the size of participating area and the total budget spent on the measures in Table A. 1 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. 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 1. 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 employed the results of the simulation and optimization for the analysis of distributional aspects. The next sections give an overview of the modelling procedure, which is implemented in the decision support software *DSS-Ecopay* (see Sturm et al., 2018 for more details on the software).

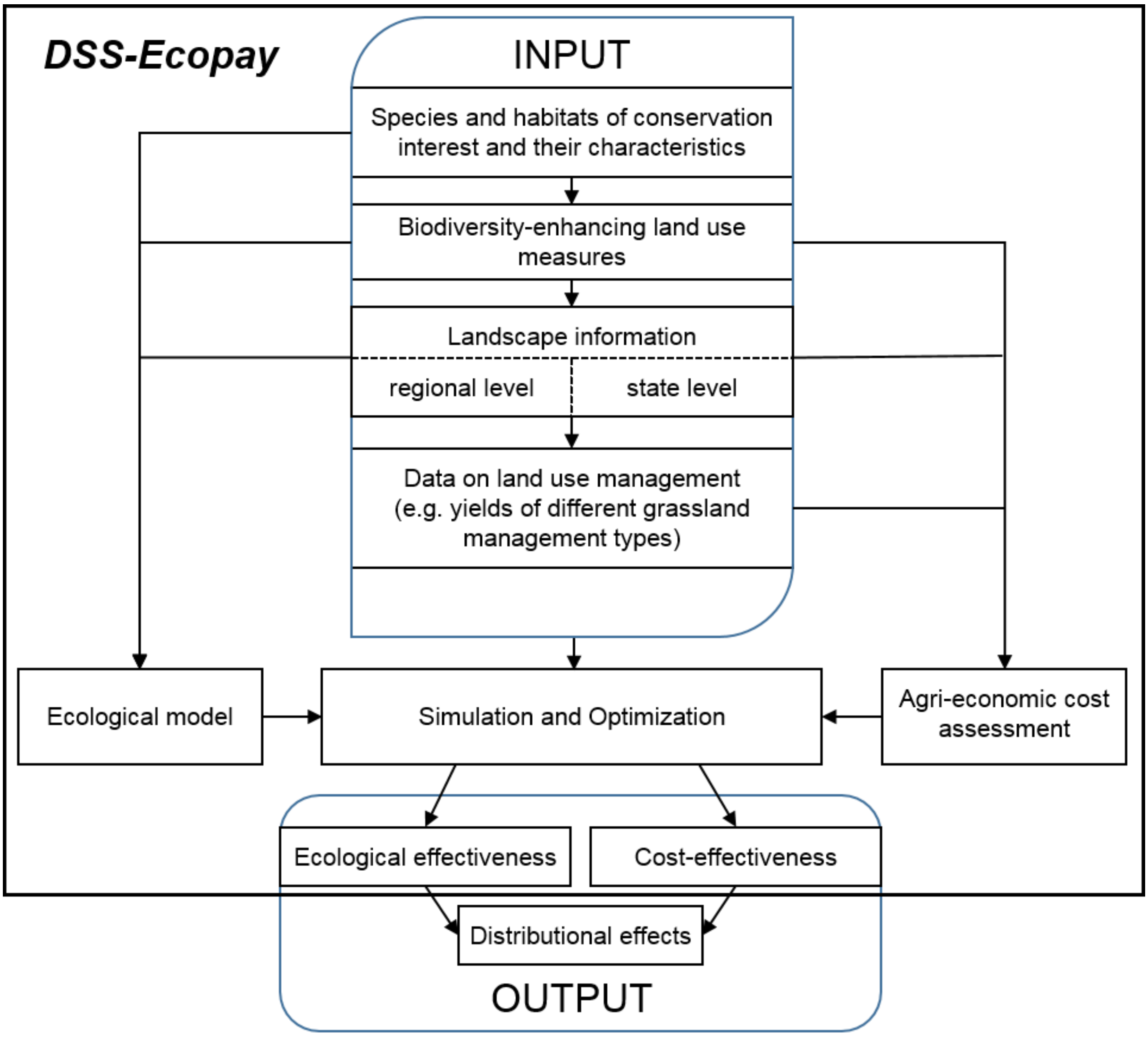


Figure 1 Components of the ecological-economic modelling procedure. Source: modified from Wätzold et al., 2016

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 (see Table A. 2) all of which are threatened or endangered. For the species and habitat types information about certain characteristics 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.

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 latter 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 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 is the size of a grid cell.

The dispersal rate of a species is 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. In the ecological-economic modeling procedure, the effective habitat area A_j^{eff} is the indicator for the impact 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 achieved 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 habitats. 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.

In order to simulate an AES, the aforementioned parameters have to be specified. A farmer (grid cell) is assumed to adopt the measure with the highest difference between payment and participation costs, i.e. with the highest producer surplus $PS^{l,m}$, as long as it is positive ($PS^{l,m}>0$) and the maximum 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 determined by calculating the effective habitat area 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} for a number of predefined species.

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

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.

The optimization is carried out with simulated annealing. Since the optimization with all available 475 land use measures leads to excessively high computation time, Wätzold et al. (2016) conduct a two-step procedure which we also follow. First, for each species and grassland type the two land use measures with the highest benefit-cost ratio (average ecological benefit of each measure divided by its average cost) is assessed. The selected measures with the best benefit-cost ratio together with the land use measures from the Saxon AES (58 measures in total) are then used in the optimization procedure. The result of the optimization is a cost-effective AES, i.e. a set of measures with the corresponding payments and effects on species (A_j^{eff}), the budget required, as well as the maximizing sum of effective habitat areas A_{tot}.

As a measure of cost-effectiveness for analyzing the trade-offs among the simulated and optimized schemes on regional level we compare the total achieved effective habitat area A_{tot} per Euro budget B spent, i.e.:

$$Eff = \frac{A_{tot}}{B} \qquad \text{Eq. 6}$$

3.6 Regionalization and distributional impacts in the modelling procedure

To investigate the cost-effectiveness of regionalization and the distributional impacts of cost-effectiveness improvements, the modelling procedure was modified in the following way. GIS data on the spatial distribution of agri-economic regions (from Saxon State Ministry of the Environment and Agriculture, 2014c) was added as an input to the model. Thus, the existing pixels could be attributed to the three regions (with small, negligible exceptions: we decided not to include pixels which cross the border between two regions). For each region, we calculated the budget spent in the simulation of the Saxon AES. The resulting regional budgets were then used in the three separate optimizations of the payments for the three regions to ensure comparability with the simulation results. Thereby, the ecological-economic modelling procedure was run separately for each region.

We use the results of the modelling procedure (the payment levels and the generated producer surplus per pixel) to compare the distributional impacts of the simulated, the optimized and the regionally optimized AES.

3.6.1 Selected fairness principles

The comparison of distributional impacts of the simulated and the optimized AES 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, i.e. compensations in AES should be equal for all farmers. This corresponds to distribution of equal payments (*P*). In our analysis we measure the equality of the distribution using the Atkinson index (see section 3.6.2 below).

The equity principle or accountability principle (Homans, 1974; Konow, 2003) stipulates that fair allocation (output) 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. Perfect equity would require payments to only cover each farmer's opportunity costs, thus generating no producer surplus. By optimizing the cost-effectiveness of an AES we actually minimize/ decrease the generated *PS*, therefore a cost-effective AES is also more equitable. Since with homogeneous payments per measure per hectare, *PS* cannot be perfectly avoided (see Ohl et al., 2008), we associate higher equity with a more equal distribution of *PS*. The equality of *PS* distribution is, as with the payments distribution, measured using the Atkinson index (section 3.6.2).

The maximin principle introduced by Rawls (1971, p. 303) states that if inequalities exist, they should be “to the advantage of the least favored”. In the context of PES, this principle has been interpreted by Pascual et al. (2010) as maximizing “the net benefit to the poorest landholders”, whereby “payments are differentiated according to the income of providers”. We apply this principle in the analysis of both the equality and equity of the simulated and optimized AES. To identify the poorest region we would ideally use individual farm income data. However, due to no data accessibility on the farm level, we compare only the mean incomes of the three regions and define the region with the lowest mean income (earnings before taxes plus personnel expenses per worker) as the poorest region. For this region - region 1 - we look at the minimum *P* (P_{min}) and minimum *PS* (PS_{min}) and compare the results of the simulation and the optimizations. The highest P_{min} and PS_{min} reached in region 1 indicate the maximin payment allocation (AES).

As mentioned above, due to data access limitations we consider one pixel as a proxy unit for a farmer. Thus, in both the analysis of equality and equity we compare the distributions of *P* and *PS* among pixels resulting from the simulation and optimizations.

3.6.2 Inequality indices

For analyzing inequality different indices, such as the Gini index, have been developed. As Atkinson (1970) argues, such inequality indices rely on implicit assumptions about the underlying social welfare function and thus attach different weights to different income levels. The comparison of any two distributions based on such indices should therefore be accompanied by a discussion of the corresponding social welfare assumptions. In our analysis we employ the Atkinson index (AI) as a measure of inequality as defined by Whitehouse (1995):

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

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

where y_i refers to individual income and $\bar{y}$ refers to the average income of individuals in population of size n. In our case y_i stands for payment (*P*) or 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 less unequal the distribution, whereby perfect equality corresponds to a value of 0 for the Atkinson index.

The calculation of the Atkinson index is based on a parameter epsilon (ε), which can reflect different levels of inequality aversion and thus different social welfare preferences. The higher the value of ε, the stronger the inequality aversion, with $\varepsilon = 0$ corresponding to no interest in the distribution and high values of ε corresponding to high inequality aversion and Rawlsian preferences. As Schlör et al. (2013) suggest, the ε parameter can be defined as a ratio between an equality parameter α and an efficiency parameter β. These parameters can each take values between 1 and 5:

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

Thus, ε ranges from 0.2 with low inequality aversion and strong efficiency preferences to 5 with high inequality aversion and Rawlsian preferences. With higher values of ε 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 and efficiency and corresponds to an inequality measure used by Champernowne (1974), where the Atkinson index equals one minus the ratio of the geometric to the arithmetic mean.

To analyze the equality and equity of the simulated and optimized AES for Saxony on a provincial and regional level, we compare the payment distributions and producer surplus distributions based on the Atkinson index with an epsilon value of 1 with the assumption that the social preferences for efficiency and equality are equally high.

We define *EP* as a measure of equality and *EPS* as a measure of equity, where:

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

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

Here *i* refers to pixels instead of individuals or farmers, due to the mentioned limitations of data accessibility.

Using these measures we transform the values of the Atkinson index so that a higher value of the equality measures indicates a less unequal (more equal) distribution.

4 Cost-effectiveness analysis

We investigate cost-effectiveness gains through an optimized AES in two ways: for Saxony as a whole and for regionalized AES.

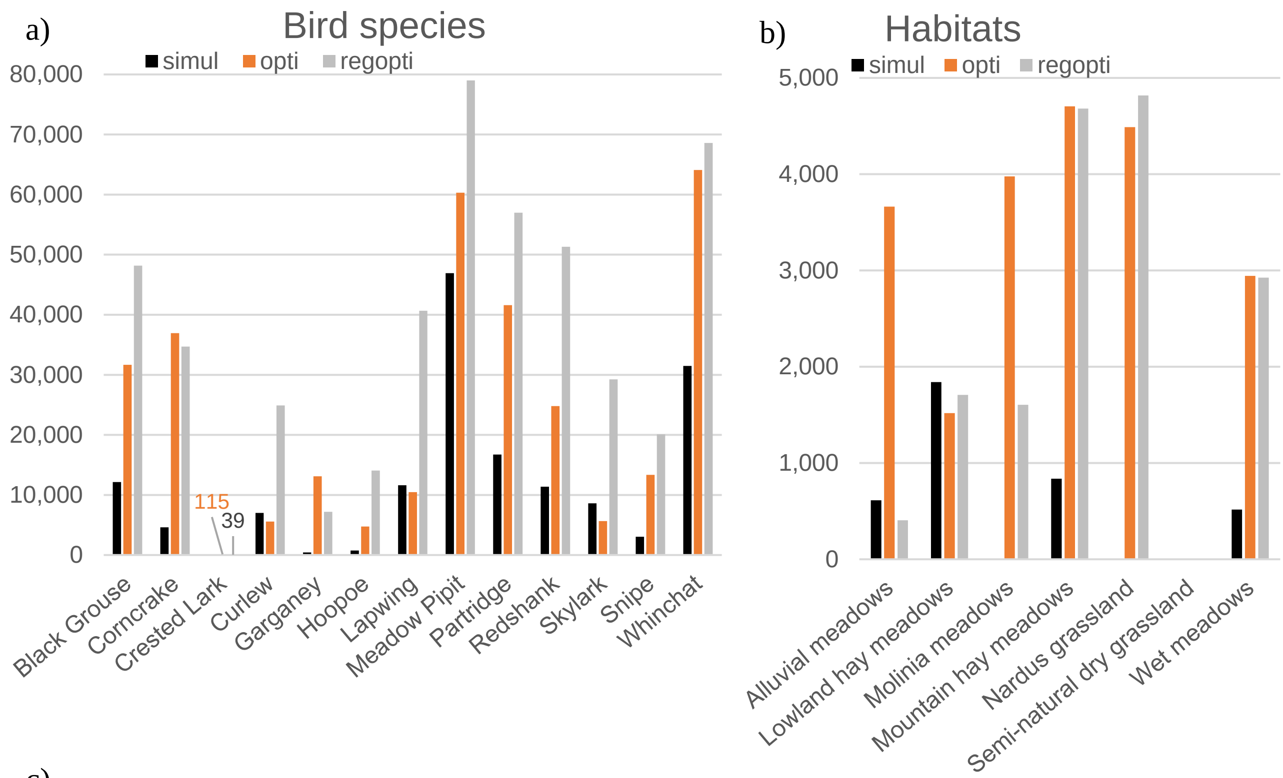
4.1 Overall optimization of the Saxon AES – Cost-effectiveness gains

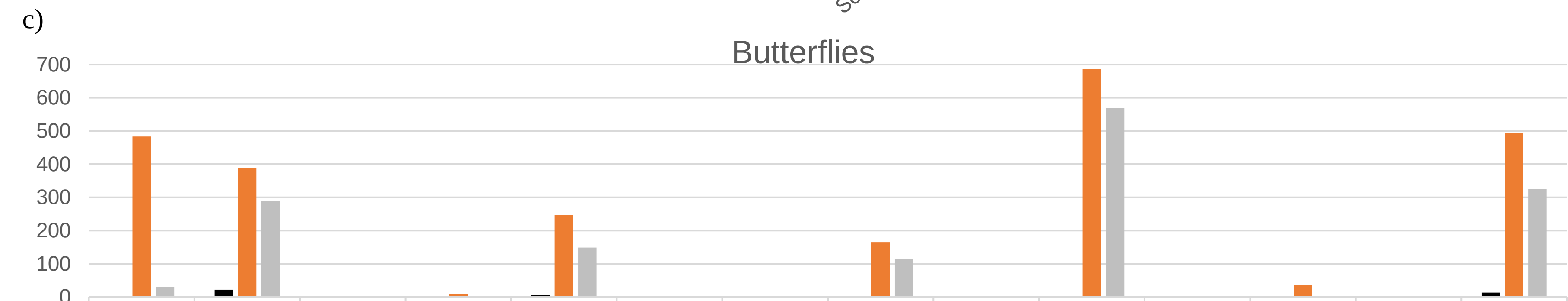
To investigate cost-effectiveness gains of optimized AES, we first simulate the impacts of the Saxon AES for grassland (Table A. 1). The main output of the simulation is the estimated effective habitat area per species and habitat type A_j^{eff} . We find that the grassland AES in Saxony contributes considerably to the conservation of endangered grassland birds, but fails to protect most of the butterfly species and habitat types (Table A. 2). All bird species, except 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.

In a second step, we carry out the optimization for a non-regionalized Saxon AES and maximize the ecological effectiveness of the AES under the given overall budget constraint, which is the total cost of AES measures in Saxony in 2013 (€ 11,092,505 as indicated in Table A. 1). The results of the overall optimization include a list of land use measures (19 measures in total), the corresponding payments per ha, the area covered by each measure, as well as the total area, and the part of the budget allocated to each measure, as well as the total budget of the cost-effective AES. For better comparability with the estimations of the regional optimizations, the mentioned results are differentiated according to agri-economic region and included in Table A. 3.

Compared to the simulated Saxon AES, the cost-effective AES leads to more than twice the total effective habitat area A_{tot} for a nearly identical budget (Table A. 2 and Figure 2). The levels of conservation are higher for almost all species and habitat types, except for the curlew, the lapwing, the skylark and lowland hay meadows (20%, 10%, 35% and 18% less achieved effective habitat area respectively). The increases in effective habitat area are substantial, from 29% for the meadow pipit up to a factor of 290 for the purple-edged copper. Moreover, the overall cost-effective AES conserves all 13 bird species, nine out of 14 butterfly species and six out of seven habitat types.

Figure 2 Comparison of the ecological effectiveness of the simulation (simul) with the overall optimization (opti) and regional optimization (regopti) for birds (a), habitat types (b) and butterflies (c). The y-axis indicates the effective habitat area A_j^{eff} 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
simul	0.00	21.96	0.00	0.00	7.30	0.00	0.00	0.65	0.00	2.36	0.00	0.00	0.00	13.31
opti	483.10	389.16	0.00	9.63	246.49	1.57	0.00	165.32	0.00	685.80	0.00	37.53	0.00	494.67
regopti	30.90	288.64	0.00	0.00	148.72	0.00	0.00	115.28	0.00	569.08	0.00	2.51	0.00	324.56

4.2 Regional optimization of the Saxon AES – cost-effectiveness gains

To investigate how regionalization affects the cost-effectiveness of the Saxon AES, we conduct separate optimization for the three agri-economic regions. To ensure comparability of the results with the Saxon AES, the budget for each region is set identical to the budget allocated to a region in the simulation. For each region the ecologic-economic modelling procedure maximizes the ecological benefit under the given budget constraint.

The regionalized cost-effective AES includes altogether 30 measures (17 in region 1, 19 in region 2 and 17 in region 3) and leads to a greater participating area as the simulated scheme and the cost-effective regionally undifferentiated scheme and also to a higher effective habitat area (Table A. 2). Compared to the simulated AES, the levels of conservation are higher for all species and habitat types, except for alluvial meadows and lowland hay meadows (34% and 7% less achieved effective habitat area respectively). The increases in effective habitat area for species range from about 68% for the meadow pipit up to a factor of 240 for the purple-edged copper. The cost-effective regionally differentiated AES conserves all 13 bird species, seven out of 14 butterfly species and six out of seven habitat types. Thus, compared to the overall optimization the regionally differentiated scheme leads to 47% higher total effective habitat area A_{tot} and performs better for bird species, but reaches a lower conservation level for butterflies and habitat types (Table A. 2 and Figure 2).

4.3 Analysis of results

In comparing our results with Wätzold et al. (2016) who also carry out an optimization of the AES for Saxony we find that they are similar. The proposed cost-effective AES in Wätzold et al. (2016) also includes substantially more measures, has lower payments for the suggested measures and covers more species and habitat types than the simulated Saxon AES. In line with Wätzold et al. (2016), we explain the cost-effectiveness gains of the proposed scheme with lower payments for the measures and the larger variety of measures that allow to tailor the measures to the requirements of individual species and of habitat type generation. Going beyond Wätzold et al. (2016), the regional differentiation of the results (Table 2) enables us to identify regional shifts of achieved effective habitat area.

In both optimizations we find a relatively lower increase in area participating in the AES in region 2 compared to the other regions, because region 2 has the highest opportunity costs for participation due to the highest average soil productivity.

Table 2 Regional comparison of the (cost-)effectiveness of the simulation, the overall and the regional optimizations.

Run	**Regions**	A_j^{eff} **birds in ha**	A_j^{eff} **butterflies in ha**	A_j^{eff} **habitats in ha**	**Total achieved** A_{tot} **in ha**	**Budget in Euro**	**Producer surplus (PS) in Euro**	**Participating area in ha**
simulation - absolute values in ha	region 1	28,755	0.65	1,225	29,981	2,104,425	1,258,621	10,500
	region 2	47,273	15	816	48,105	2,905,838	1,498,020	23,806
	region 3	78,702	30	1,763	80,495	6,129,313	4,467,608	22,975
optimization - as percent difference to simulation	region 1	107%	14,384%	59%	106%	-20%	-33%	79%
	region 2	82%	316%	89%	83%	-23%	-12%	14%
	region 3	112%	7,841%	910%	132%	18%	-57%	58%
regional optimization - as percent difference to simulation	region 1	245%	6,907%	-10%	235%	-0.04%	-47%	104%
	region 2	193%	- 15%	26%	190%	-0.05%	-16%	35%
	region 3	201%	4,691%	695%	214%	-0.04%	-59%	68%

In general the achieved effective habitat areas from the optimizations are higher than from the simulation in all regions with the exception of the effective area for butterflies in region 2 and the effective area for habitat types in region 1 in the regional optimization (Figure A. 3, Figure A. 4, Figure A. 5). The regional optimization is better than the overall optimization for birds, but worse for butterflies and habitat types. Thus, regionalization helps in further increasing the level of conservation of birds, but not for butterflies and habitat types. It seems that regionally undifferentiated payments are better for the conservation of butterflies and habitat types, whereas birds are best protected with differentiated payments. Despite lower budgets in regions 1 and 2, compared to the regional optimization and the simulation, the overall optimization is best for butterflies and habitat types. Surprisingly, the larger participating area in regions 1 and 2 in the regional optimization does not lead to higher conservation levels of butterflies and habitat types. This suggests that for the protection of butterflies and habitat types the combination of measures may be a more crucial determinant than the amount of payments and the area covered. Compared to the regional optimization the overall optimization leads to overall 11% less participating area than the regional optimization, higher participating area for the measure categories mowing strips and seasonal grazing and lower participating area for the other measure categories (mowing, mowing and pasture and rotational grazing) in all regions. Mowing strips are a good measure for promoting butterflies in grasslands (Bruppacher et al., 2016) and are represented with 23% larger area in the overall optimization than in the regional scheme. Seasonal grazing, the most expensive measure category, is only very slightly represented in the regional optimization and not at all used in the simulation, whereas in the overall optimization it is implemented in all regions. The participating area is thereby 31 times larger in the overall than in the regional optimization.

Compared to the simulated Saxon AES, the cost-effective set of measures in the overall optimization leads to very large effective habitat area in region 2 for alluvial meadows and a shift of effective habitat area from region 2 to region 3 for lowland hay meadows, mountain hay meadows and wet meadows. In the regionalized optimized scheme no effective habitat area for alluvial meadows is established in region 2, which might be a reason for the lower A_j^{eff} for butterflies in this region compared to the overall optimization. Alluvial meadows are a habitat for many butterfly species, but usually cover only small patches of land and are under threat of complete destruction (Saxon State Ministry of the Environment and Agriculture, 2019). Moreover, butterflies have low dispersal distances and depend strongly on the suitability of habitat types, and therefore require a network of suitable habitat fragments across regions to ensure population viability (Ekroos et al., 2016).

Since no weighing of species importance is assumed in the calculation (Eq. 5), the achieved effective habitat area is always larger for birds (due to their larger dispersal distances, more frequent occurrence, and the fact that they can survive on multiple habitat types (Ekroos et al., 2016)). A way to make an optimized scheme more suitable for butterflies or habitat types in the modelling procedure would be to define higher weights for the corresponding species.

In the end, the different sets of measures in the optimizations lead to different achieved effective habitat area. For an overview of the types of measures involved per region in the simulation and the optimizations, see Figure A. 3.

5 Analysis of distributional impacts

5.1 Overall Comparison for Saxony

The overall comparison of the equality (*EP*) and equity measures (*EPS*) for Saxony is shown in the lowest panel of Figure 3. In the simulation, since the payments are homogeneously distributed, but costs not, the payments are more equally distributed than the producer surplus ($EP>EPS$). In the overall and regional optimizations, the producer surplus ($PS = P - c$) is minimized and thus more equally distributed than the payments ($EPS>EP$).

Comparing the simulation with the optimizations: the payments are more equally distributed in the simulation, whereas in the optimizations the producer surplus is minimized and thus more equally distributed than in the simulation. The regionally differentiated optimization leads to a more equal distribution of payments than the overall optimization, but less equal distribution of producer surplus, i.e. the regional optimization leads to less inequality (higher *EP*), but also to less equity (lower *EPS*) than the overall optimization. This equality equity trade-off is shown in Figure 3.

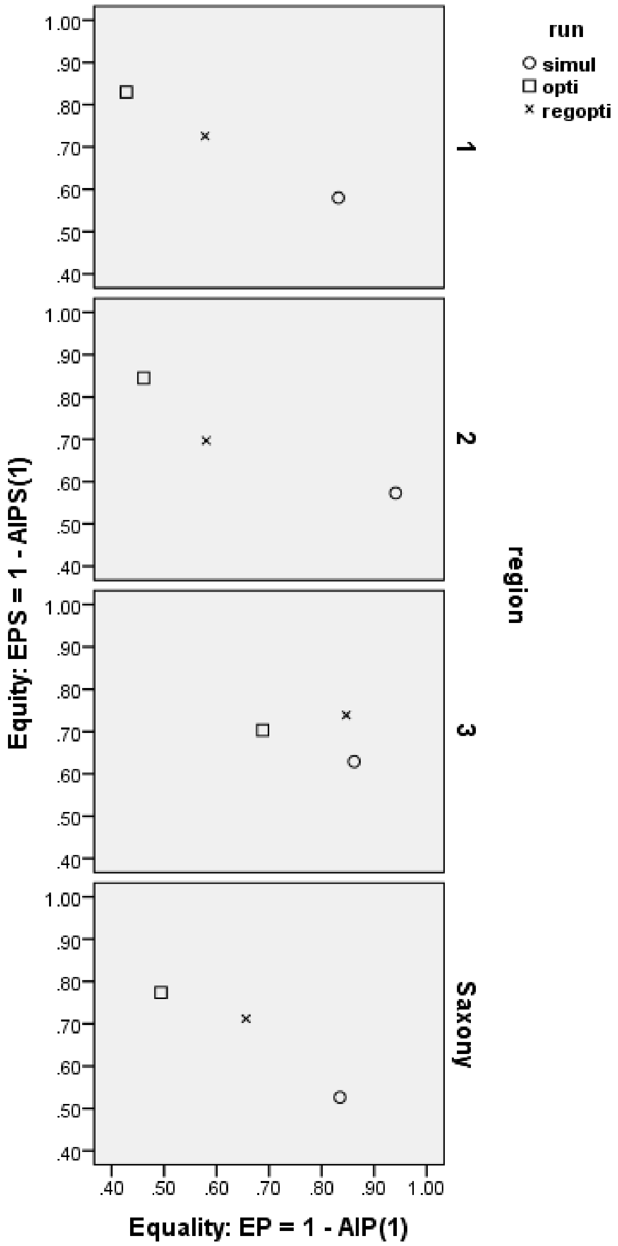


Figure 3 Equality-Equity trade-off in the optimization of the Saxon AES for the three regions and for Saxony as a whole.

5.2 Regional Comparison

As in the overall comparison of the *P*-distribution, the payments are more equally distributed in the simulation than in the optimizations in each region (Figure 3 - comparison of *EP* values from the simulation versus the optimizations for each region). Through the optimizations the *P*-distribution gets more unequal in all three regions, i.e. higher cost-effectiveness leads to greater inequality. The overall optimization leads to a greater rise in inequality than the regional optimization. In general, compared to the simulation in the optimizations the *P*-distribution of regions 1 and 2 changes more than the *P*-distribution in region 3.

The optimizations have the opposite effect on the producer surplus than on the payments (Figure 3 - comparison *EPS* values from the simulation versus the optimizations for each region). The producer surplus gets more equally distributed and the *PS*-distributions in the three regions get similar, especially very similar in the regional optimization. This means, optimization, the increase in cost-effectiveness, leads to an increase in equity. In regions 1 and 2 the overall optimization leads to more equitable *PS*-distribution than the regional optimization, in region 3 it is the other way around.

5.3 Regional Comparison based on Rawls maximin principle: maximizing the minimum payments (P_{min}) and producer surplus (PS_{min})

To account for Rawlsian preferences, we focus on region 1, the region with the lowest mean income (expressed as EBT plus personnel costs per worker), and compare the minimum outcomes of the simulation and optimizations (i.e. P_{min} and PS_{min}). The simulation is thereby always better than the optimizations, not only in region 1, but in all three regions, since in the simulation P_{min} and PS_{min} are maximized (cf. Table 3). Thus, when taking into account Rawlsian preferences, the simulation is better than both optimizations on both the equality and the equity criterion. On the maximin criterion, the regional optimization is better than the overall optimization, since compared to the overall optimization it leads to higher (though still very low) minimum producer surplus in all regions (and to the same minimum payments in regions 1 and 2 and a higher minimum payment in region 3).

Table 3 Regional comparison of the minimum payments (P_{min}) and producer surplus (PS_{min}) from the simulation and optimizations (values in Euro).

Region	**Variable - P_{min} or PS_{min} per region**	**Simulation (maximin)**	**Overall optimization**	**Regional optimization**	**Mean income (EBT + pers. costs/ worker)**
1	$P1_{min}$	**79.00**	16.78	16.78	**31,464**
2	$P2_{min}$	79.00	16.78	16.78	38,139
3	$P3_{min}$	79.00	16.78	43.20	32,693
1	$PS1_{min}$	**8.22**	0.16	1.17	**31,464**
2	$PS2_{min}$	8.22	0.16	0.50	38,139
3	$PS3_{min}$	8.22	0.16	1.19	32,693

6 Analysis of the equality / equity vs. cost effectiveness trade-offs

As suggested by the comparison of the payment distributions and producer surplus distributions in the simulation and the optimizations, on the criterion of equality the simulation is superior to the optimizations; on the criterion of equity (accountability) the optimizations are superior to the simulation, except in the case of Rawlsian preferences.

In general, the payments are most homogeneously distributed in the simulation, therefore highest equality is, in general, reached there, however with lowest cost-effectiveness. The highest cost-effectiveness in terms of A_{tot} per Euro is reached by the regional optimization, as it generates highest A_{tot}.

In regions 1 and 2 the regional optimization is most cost-effective and leads to higher equality than the overall optimization, but to lower equality compared to the simulation. In region 3 the regional optimization is not only most cost-effective, but it also reaches similar equality level as the simulation (panel 3 in Figure 4a). There the cost-effectiveness equality trade-off is not that prominent and for only 2% sacrifice in equality 235% increase in cost-effectiveness can be reached. It should be noted, however, that the regional optimization leads to less effective habitat area for butterflies and habitat types than the overall optimization.

In region 3 regionalized payments achieve about 40% less effective habitat area for butterflies and 20% less for habitat types (but also about 40% greater effective habitat area for birds) than optimized homogeneous payments. In the simulation and the regional optimization region 3 receives three respectively two times higher budget than region 1 and 2, in the overall optimization the proportions are even higher – four and three times higher budget in region 3. Region 3 is the region with lowest average soil productivity grassland number, with the highest number of farms and lowest average farm size, i.e. many small farms with relatively low income are in this region and they might be more willing to participate in an AES than farms with higher soil productivity and income from region 2. Region 1 has in general three times lower agricultural area covered by grassland farms (as defined in section 2.1) than the other two regions.

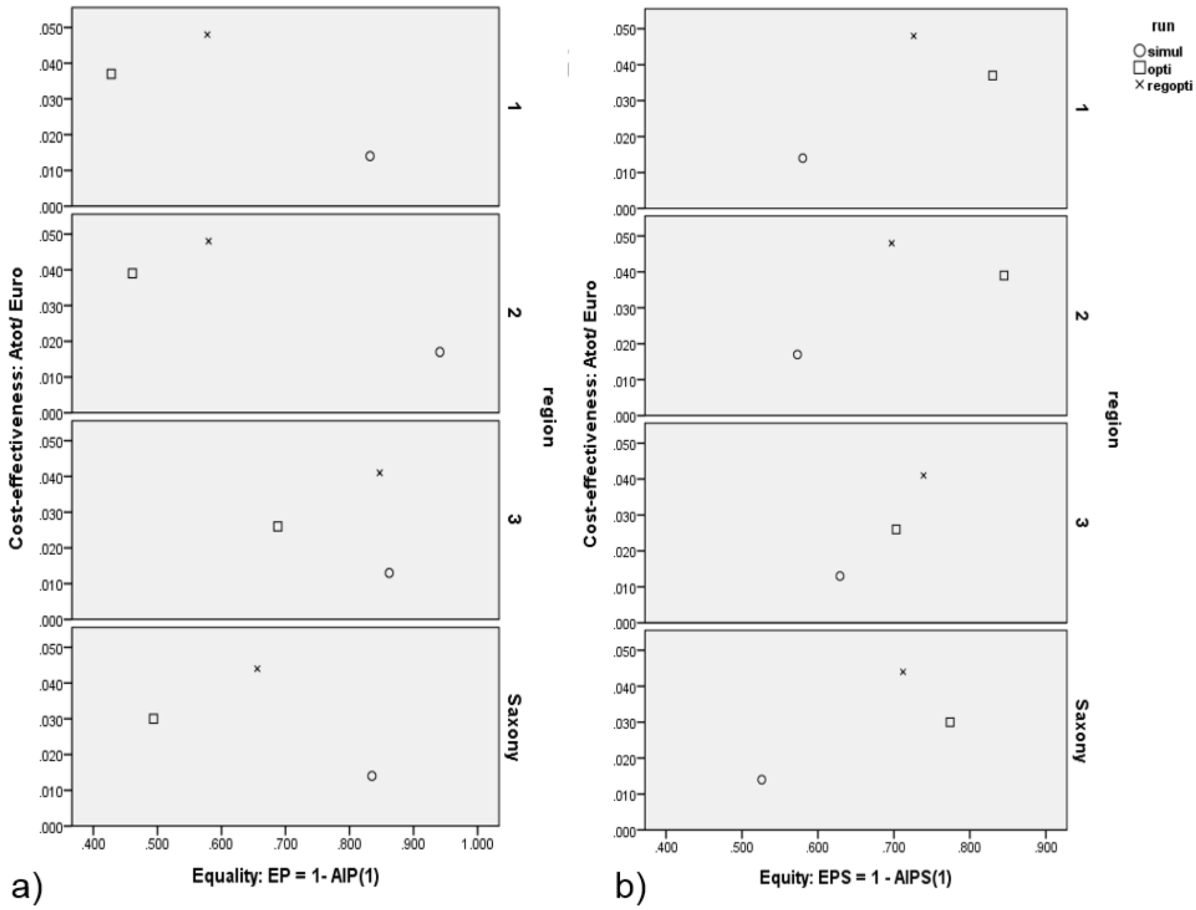


Figure 4 Cost-effectiveness equality (a) and equity (b) trade-offs of overall and regional AES optimization in the three regions and for whole Saxony.

The producer surplus is most homogeneously distributed in the overall optimization, therefore highest equity is, in general, reached there (Figure 4b). As a whole, the trade-off cost-effectiveness versus equity is not that prominent, since in comparison to the simulation the more cost-effective optimizations reach also higher equity levels. However, highest cost-effectiveness is generally achieved with regionally differentiated payments, which on the other hand lead overall to less equity (equality in *PS*-distribution). In general, increasing cost-effectiveness (A_{tot}/Euro) leads to more equity, however, the more cost-effective regionally differentiated scheme leads to less equity than the overall optimization.

Only in region 3, the regional optimization is not only most cost-effective, but also reaches highest level of equity (panel 3 in Figure 4b). There regional differentiation leads to 5% more equity and 59% more cost-effectiveness than the overall optimization. In the other two regions regional optimization leads to more cost-effectiveness, but less equity. For Saxony as a whole regional optimization leads to 8% less equity and 46% more cost-effectiveness than the overall optimization. Again, it should be noted, that the regional optimization leads to less effective habitat area for butterflies and habitat types than the overall optimization.

Thus, our measure of cost-effectiveness (A_{tot}/Euro) has some limitations, since with giving all species equal weights in the modelling procedure the achieved effective habitat area A_j^{eff} is always larger for birds (due to their larger dispersal distances, less specialization or reliance on certain habitat types, and in general more frequent occurrence in the landscape) than for butterflies, and for habitat types. Thus a larger A_{tot} does not necessarily indicate higher effectiveness for butterflies and habitat types.

We have tested the sensitivity of the A_{tot}/Euro comparison giving higher weights to the A_j^{eff} of butterflies and habitat types (using the ratios of A_j^{eff} for birds and habitats reached by the overall optimization divided by the corresponding A_j^{eff} from the simulation - 54.6 for butterflies and 5.6 for habitats) and this does not lead to qualitative changes in overall cost-effectiveness and in the comparison of different schemes within the regions. However, the comparison of cost-effectiveness between the regions in each optimization changes (since region 3 with the highest A_{tot} and highest A_j^{eff} for butterflies and habitats gets most of the weighting effect). Since we are not focusing on the comparison between the three regions themselves, the sensitivity of our measure of cost-effectiveness is thus low.

A way to make the optimized schemes more suitable for butterflies or habitat types in the procedure would be to define higher weights for the corresponding species in the first place – directly in the optimization procedure.

7 Discussion and conclusion

Spatial differentiation of payments and accounting for distributive goals are challenging issues in the design of agri-environmental schemes. More so due to the focus on efficiency, or cost-effectiveness, of this policy instrument in the public debate.

Here we analyze the trade-offs between achieving distributive goals and cost-effectiveness and test the influence of spatial differentiation (regionalization) for the case study of a grassland AES in Saxony. We compare a simulated Saxon AES to a more cost-effective optimized scheme and to a more cost-effective regionally optimized scheme.

Compared to the simulated Saxon AES the optimized schemes lead to a great rise in cost-effectiveness reaching much greater species protection with similar budgets. The rise in cost-effectiveness gives rise to more inequality. On Rawls criterion, the simulation is superior to both optimizations, and the regional optimization is better than the overall optimization.

Thus, if we choose fairness as the goal and equality or Rawls' maximin criterion as fairness principle, the simulated scheme is superior to the more cost-effective, optimized ones. However, if we look at fairness as equity, and choose accountability as the fairness principle, then the increase in cost-effectiveness leads to more equity and the optimized schemes are more equitable. Since the accountability principle is considered as more efficiency focused (cf. Pascual et al., 2010), the optimizations still reduce the overall fairness of the scheme. Uthes et al. (2010b) also come to the conclusion that effectiveness and efficiency are sacrificed with the usual design of AES with homogeneous payments and with the additional goal of rural income creation. They suggest 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."

With regard to the effects of regionalization on cost-effectiveness overall (on the provincial, as well as on the regional level) the regional optimization is more cost-effective than the overall optimization for birds, but it is worse for butterflies and habitat types. Thus, regionalization (i.e. spatial differentiation) helps in further increasing the level of conservation of birds (which is in line with the results of Armsworth et al., 2012), but not for butterflies and habitat types. As already mentioned, butterflies have low dispersal distances and depend strongly on the suitability of habitat types, and therefore require a network of suitable habitat fragments across regions to ensure population viability (Ekroos et al., 2016).

Despite somewhat lower budgets[1] in regions 1 and 2, compared to the regional optimization and the simulation, the overall optimization is best for butterflies and habitat types. Surprisingly, the larger participating area in regions 1 and 2 in the regional optimization does not lead to higher conservation levels of butterflies and habitat types. This suggests that for the

[1] The regional budgets in the regionally differentiated schemes were set identical to the regional budgets in the simulation, whereas in the overall optimization over Saxony only the total budget was fixed, the regional budgets resulted from the optimization itself and are therefore somewhat different.

protection of butterflies and habitat types the combination of measures may be a more crucial determinant than the amount of payments and the area covered.

The regional optimization is better than the overall optimization on the equality criterion (both on the provincial and regional level), but on the provincial level on the equity criterion the overall optimization is better than the regional one. On the regional level the overall optimization leads to greater equity than the regional optimization in two out of 3 regions. Thus, regional optimization leads to higher cost-effectiveness for birds and to more equality, i.e. less inequality, but also to less equity, than the overall optimization. Region 3, with the highest number of grassland farms and smallest average farm size, is an exception, where regional optimization leads to (near) win-win situations. In region 3 the regionally differentiated scheme leads to 5% more equity and 59% more cost-effectiveness than the overall optimized scheme, and compared to the simulated AES for only 2% sacrifice in equality 235% increase in overall cost-effectiveness can be reached. However, for butterflies and habitat types, the regional payments are less (cost-)effective than the homogeneous optimized scheme.

For our analysis we have applied three strictly defined social fairness principles relevant for the distribution of payments to farmers. We, however, acknowledge that there are multiple dimensions of fairness and pursuing different fairness objectives can lead to different conclusions or outcomes (Law et al., 2018). If we look at existence values, intergenerational equity and responsibility to other species as environmental justice principles the fairness comparison will depend strongly on the number of species conserved through an AES and the extent to which they are conserved.

Here we use conceptual/ theoretical optimized AES for analysis and comparison and they consist of a large number of measures which is associated with high transaction costs (Wätzold et al., 2016). Transaction costs in AES implementation are one promising field for 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.

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Appendix:

Tables:

Table A. 1 Measures according to Directive "Agricultural environmental measures and forestation" (AuW/2007), part A, section G , "Extensive grassland use, nature conforming grassland management and conservation" [2] (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) 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) 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

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)

[2] Directive/ Richtlinie AuW/2007, Teil A, Extensive Grünlandwirtschaft, Naturschutzgerechte Grünlandbewirtschaftung und Pflege

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

Species or Habitat types	Simulation A_j^{eff} in ha	Overall optimization A_j^{eff} in ha	Regional optimization A_j^{eff} in ha
Birds			
Black Grouse	12,139.77	31,673.09	48,181.87
Corncrake	4,618.03	36,930.39	34,702.50
Crested Lark	0.00	115.30	39.29
Curlew	7,014.24	5,582.07	24,904.56
Garganey	434.62	13,098.87	7,198.65
Hoopoe	762.49	4,751.58	14,053.32
Lapwing	11,618.22	10,472.03	40,667.44
Meadow Pipit	46,921.47	60,310.84	79,009.30
Partridge	16,715.04	41,608.05	56,977.90
Redshank	11,378.51	24,791.35	51,328.70
Skylark	8,615.30	5,638.84	29,255.22
Snipe	3,031.74	13,353.78	20,072.38
Whinchat	31,481.10	64,087.24	68,591.60
Butterflies			
Amanda´s Blue	0.00	483.10	30.90
Chestnut Heath	21.96	389.16	288.64
Dingy Skipper	0.00	0.00	0.00
Dusky Large Blue	0.00	9.63	0.00
Five-spot Burnet	7.30	246.49	148.72
Glanville Fritillary	0.00	1.57	0.00
Large Wall Brown	0.00	0.00	0.00
Marsh Fritillary	0.65	165.32	115.28
Mazarine Blue	0.00	0.00	0.00
Purple-edged Copper	2.36	685.80	569.08
Scarce Large Blue	0.00	0.00	0.00
Silver-spotted Skipper	0.00	37.53	2.51
Small Blue	0.00	0.00	0.00
Woodland Ringlet	13.31	494.67	324.56
Habitat types			
Alluvial meadows	612.50	3,662.33	405.00
Lowland hay meadows	1,840.14	1,517.33	1,707.12
Molinia meadows	0.00	3,977.48	1,604.25
Mountain hay meadows	836.35	4,704.47	4,681.08
Nardus grassland	0.00	4,489.39	4,818.12
Semi-natural dry grassland	0.00	0.00	0.00
Wet meadows	515.63	2,943.75	2,925.01
Total achieved effective area A_{tot}*	**158,580.71**	**336,221.44**	**492,602.99**
Subtotal A_j^{eff} birds **% of targeted species covered**	**154,730.52** **92.31%**	**312,413.41** **100.00%**	**474,982.73** **100.00%**
Subtotal A_j^{eff} butterflies **% of targeted species covered**	**45.58** **35.71%**	**2,513.28** **64.29%**	**1,479.69** **50.00%**
Subtotal A_j^{eff} habitats **% of targeted species covered**	**3,804.61** **57.14%**	**21,294.75** **85.71%**	**16,140.58** **85.71%**
Total participating area in ha	**57,281.25**	**82,225.00**	**92,175.00**

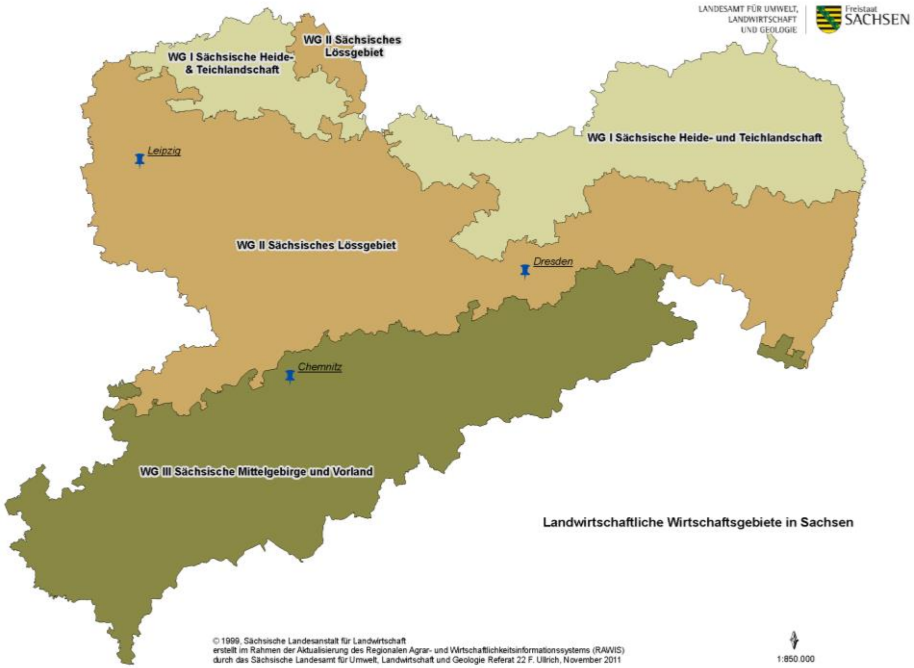
Note: * equals the sum of column values

Table A. 3 Results from the overall optimization of the Saxon AES (in sum 19 measures, 14 in region 1, 13 in region 2 and 19 in region 3)

Land use measure	Code[2]	Payment	Participating area per measure and region in ha			Total participating area per measure in ha	Budget per measure and region in €			Total budget per measure in €
			Region 1	Region 2	Region 3		Region 1	Region 2	Region 3	
Mowing	24/6/0.0 D	211.15	0.00	0.00	268.75	268.75	0.00	0.00	56,747.37	56,747.37
Mowing	26/8/0.0 D	253.70	1,356.25	18.75	6,256.25	7,631.25	344,073.84	4,756.78	1,587,179.34	1,936,009.97
Seasonal grazing	15/0/0.1.5 LU	389.97	212.50	318.75	881.25	1,412.50	82,869.05	124,303.58	343,662.83	550,835.45
Seasonal grazing	21/0/0.1.5 LU	361.17	81.25	0.00	1,493.75	1,575.00	29,345.39	0.00	539,503.66	568,849.05
Seasonal grazing	25/0/0.3 LU	370.89	75.00	468.75	12.50	556.25	27,816.38	173,852.34	4,636.06	206,304.78
Seasonal grazing	27/0/0.3 LU	357.26	518.75	1,300.00	3,187.50	5,006.25	185,329.14	464,439.30	1,138,769.44	1,788,537.88
Seasonal grazing	29/0/0.3 LU	373.38	625.00	75.00	2,143.75	2,843.75	233,361.88	28,003.43	800,431.23	1,061,796.53
Mowing and pasture comb.	19/6/0.1.5 LU	285.86	112.50	0.00	356.25	468.75	32,159.14	0.00	101,837.27	133,996.41
Mowing and pasture comb.	25/6/0.3 LU	271.85	537.50	337.50	1,800.00	2,675.00	146,119.91	91,749.71	489,331.80	727,201.43
Mowing and pasture comb.	26/6/0.3 LU	386.28	37.50	0.00	675.00	712.50	14,485.58	0.00	260,740.35	275,225.93
Mowing	26/6/6.0 D	131.89	0.00	6.25	6,187.50	6,193.75	0.00	824.32	816,075.56	816,899.88
Mowing (1)	27/6/6.0 D	138.53	0.00	0.00	31.25	31.25	0.00	0.00	4,328.94	4,328.94
Rotational grazing	25/6/6.99 LU	127.93	456.25	550.00	2,618.75	3,625.00	58,368.52	70,362.05	335,019.31	463,749.88
Rotational grazing	30/4/6.99 LU	166.23	650.00	2,106.25	2,143.75	4,900.00	108,048.85	350,119.83	356,353.42	814,522.10
Mowing and pasture comb.	20/6/6.99 LU	94.98	100.00	437.50	50.00	587.50	9,497.67	41,552.31	4,748.84	55,798.81
Mowing and pasture comb.	22/6/6.99 LU	136.62	0.00	25.00	200.00	225.00	0.00	3,415.45	27,323.60	30,739.05
Mowing and pasture comb.	27/6/6.99 LU	174.26	1,125.00	3,256.25	1,031.25	5,412.50	196,036.88	567,417.84	179,700.47	943,155.19
Mowing and pasture comb.	22/16/0.99 LU	344.29	0.00	0.00	168.75	168.75	0.00	0.00	58,098.43	58,098.43
Mowing strips (2)	19/6/6.1 D	16.78	12,912.50	18,281.25	6,737.50	37,931.25	216,621.39	306,688.08	113,028.97	636,338.44
Total			**18,800.00**	**27,181.25**	**36,243.75**	**82,225.00**	**1,684,135.61**	**2,227,485.02**	**7,217,516.88**	**11,129,135.50**

Note: [2] 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. Further, 0D (1D) indicates that N-fertilizer is not (only after the first cut) allowed, while LU indicates the maximum grazing livestock unit permitted. For example, "mowing 24/6/0.0 D" means that the first cut is not allowed before the 24QM, a second cut is allowed six weeks later, and the 0 means there is no difference between the second and third cut, that is, there is no third cut, and the use of N fertilizer is not allowed. As another example "seasonal grazing 25/0/0.3 LU means grazing can start at 25QM with no restriction afterwards, except that the maximum grazing livestock units shall not exceed 3LU. (1) corresponds to measure G3b in Table A. 1 and (2) corresponds to G9.

Figures:



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)

Figure A. 1 Agri-economic regions in Saxony. Source: modified from Saxon State Ministry of the Environment and Agriculture. 2014c.

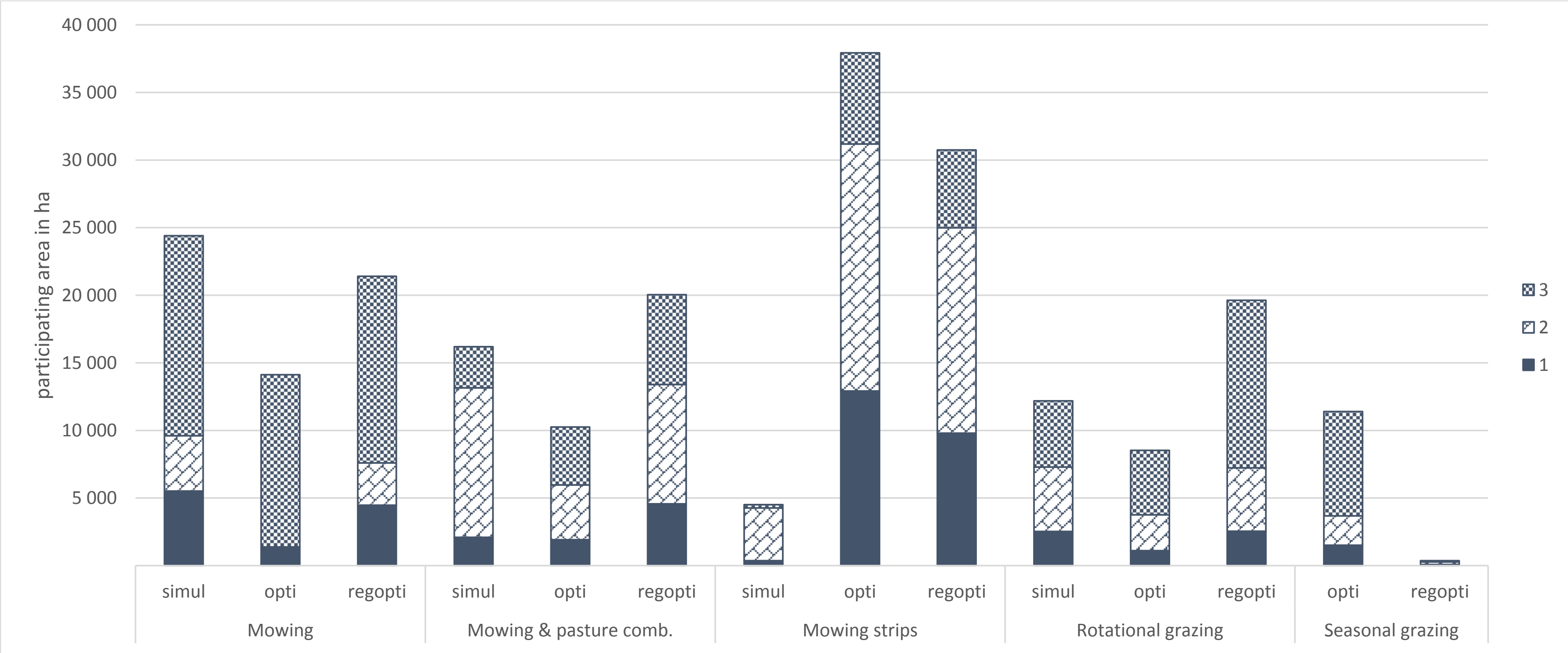


Figure A. 2 Overview of participating area per region (1, 2, 3) per category of measure for the simulation (simul), the overall optimization (opti) and the regional optimization (regopti)

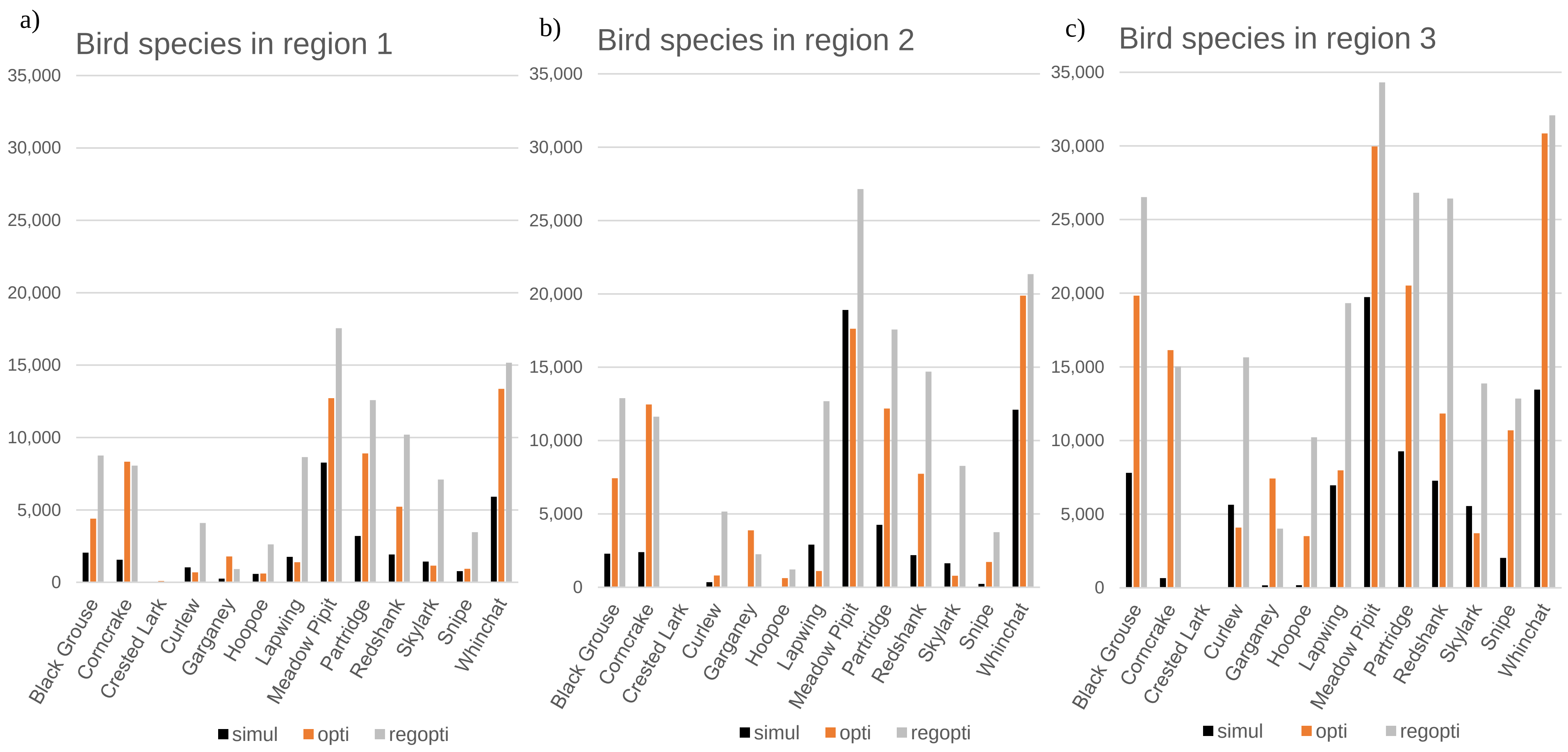


Figure A. 3 Regional comparison of the ecological effectiveness of the simulation (simul), the overall optimization (opti) and regional optimization (regopti) for birds in region 1 (a), region 2 (b) and region 3 (c). The y-axis indicates the effective habitat area A_j^{eff} achieved for each species.

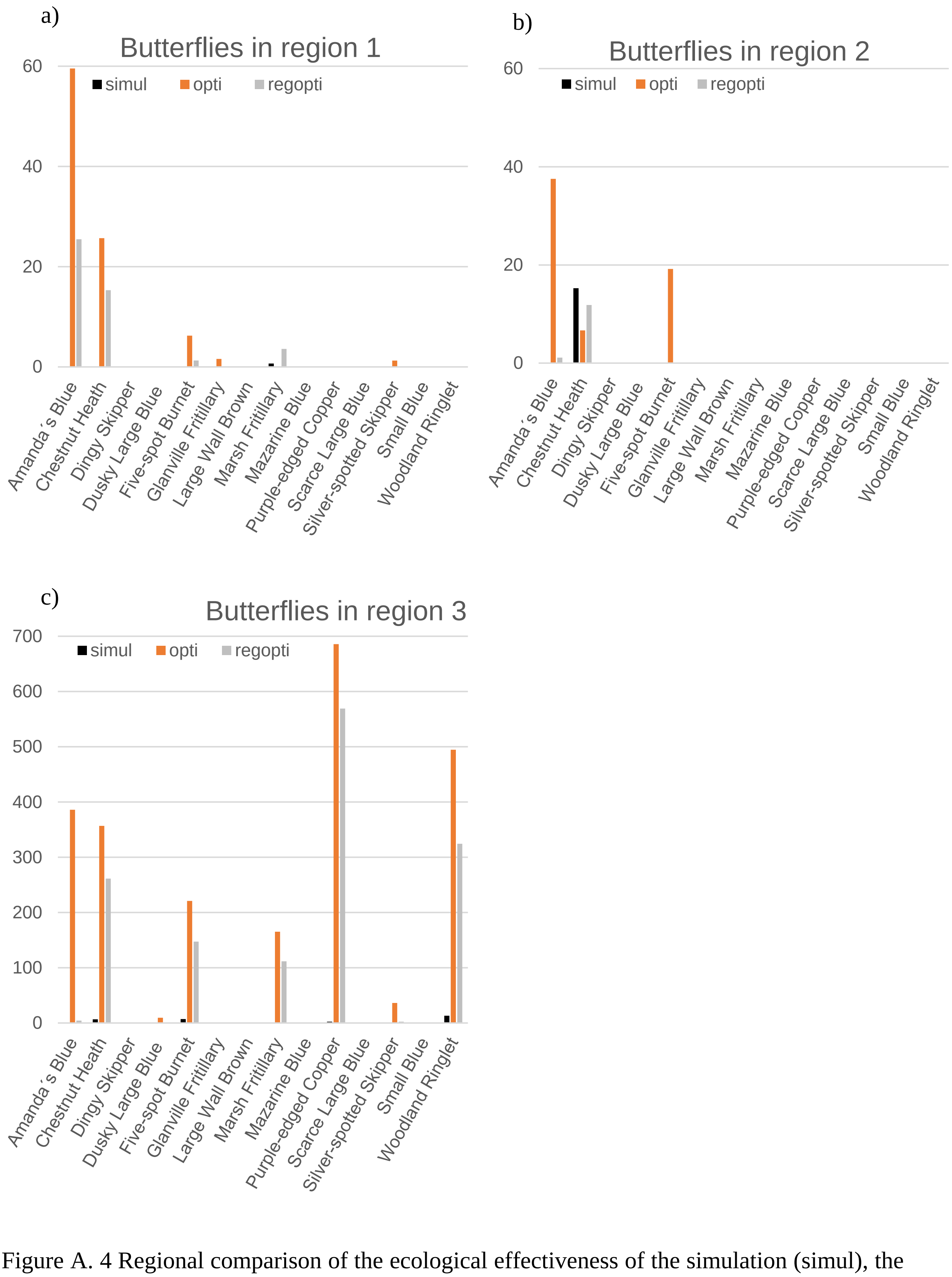


Figure A. 4 Regional comparison of the ecological effectiveness of the simulation (simul), the overall optimization (opti) and regional optimization (regopti) for butterflies in region 1 (a), region 2 (b) and region 3 (c). The y-axis indicates the effective habitat area A_j^{eff} achieved for each species.

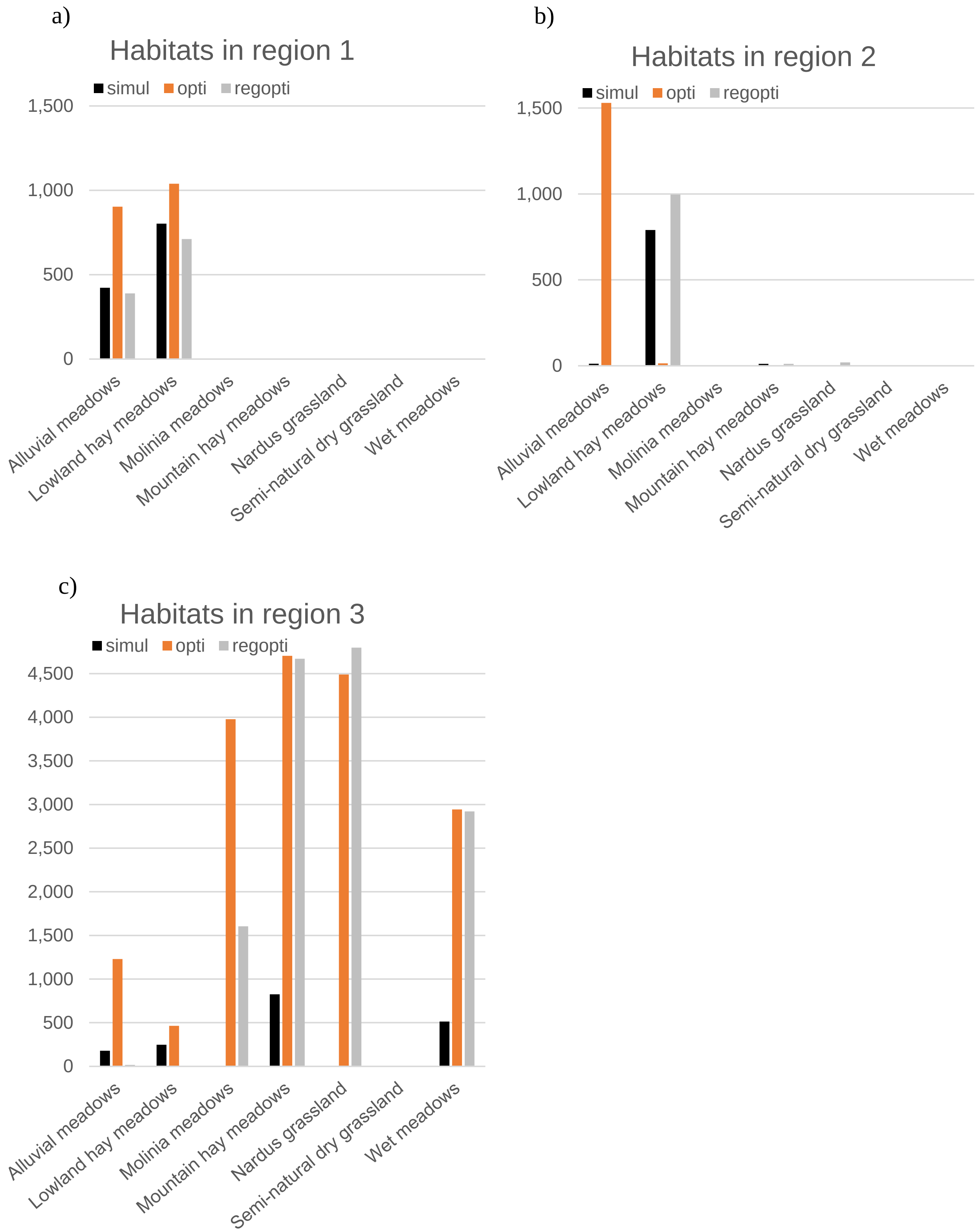


Figure A. 5 Regional comparison of the ecological effectiveness of the simulation (simul), the overall optimization (opti) and regional optimization (regopti) for habitat types in region 1 (a), region 2 (b) and region 3 (c). The y-axis indicates the effective habitat area A_j^{eff} achieved for each species.